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TEXTILE RESEARCH JOURNAL

VOL. XVIII, No. 2 February, 1948

Cotton—A Versatile Textile Fiber

Earl E. Berkley*

Abstract

Certain recent researches on cotton are reviewed, together with further data on natural variations of it as found on the cottonseed and modifications of the fiber by chemical and physical treatments. No attempt has been made to present a general review. A more extensive over-all treatment of cotton quality may be found in a report by the Bureau of Plant Industry [11].

Cotton fibers grow first in length, then in thickness. The physical properties of the fiber and, therefore, its use value are determined by its length, fineness, and cell-wall construction, all of which are genetically controlled but are also subject to modifications by weather conditions during growth. Since fiber length is established before the cell walls thicken, length and cell-wall structure may be influenced independently. As growth proceeds there is a general trend toward compensation of loss of fiber length by added strength and vice versa; however, the failure of weather conditions to remain the same throughout the growing period of the fiber may result, for example, in short, weak fiber or long, strong fiber.

Cotton fibers may be modified by swelling treatments while tension is applied. Such treatments may increase the fiber strength at the expense of other properties.

The spinning quality of cotton is dependent upon a combination of fiber properties and upon the spinning technique used. In general, however, the size of yarn or thread made from cotton is dependent upon its fiber length. For a given length, fiber fineness, and even strength, may influence the maximum count to be expected. Strong yarns require relatively strong fiber for any given fiber length and fineness.

Uniformity of fiber length undoubtedly influences the ease of manufacture and the percentage of waste to be expected from a given cotton, but it is indicated that well-bred modern varieties have sufficient length uniformity to give good results. Within a variety, however, growth conditions, ginning, and baling may affect the fiber-length uniformity enough to influence fiber property-yarn strength relationships.

Since variety characteristics may be influenced by growth conditions, causing positive varietal relationships to reverse and become negative for environment, the analyses of data consisting of fiber properties and yarn strengths, except for very general treatments, will give more information if variety and environmental effects can be segregated.

It is indicated that if good certified seed of suitable varieties for each type of environment are planted, cotton of acceptable quality can be produced throughout the Cotton Belt. In selecting a cotton for specialized uses, variety and growth conditions as well as grade and staple should be considered for best results.

Origin of Fiber

The cotton fiber has its origin in a single cell which forms on the outer covering, or epidermis, of the cotton seed. The fiber develops by an expansion and elongation of the outer wall—that is, the exposed surface of the cell (Figure 1). The first fiber initials [3, 22] are differentiated from the neighboring cells on or about the day the flower opens.

The first fiber initials appear on the broad or chalazal end of the seed (Figure 2A). As they elongate, more initials emerge and they appear progressively nearer and nearer the tip, or micropylar, end of the seed (Figure 2B). Fiber initials continue to appear for 3 to 5 days, or even longer in certain

*National Cotton Council of America. These data were presented in a lecture at the annual meeting of the Textile Research Institute, New York, November 13, 1947, while the author was a member of the Bureau of Plant Industry, U. S. Department of Agriculture.

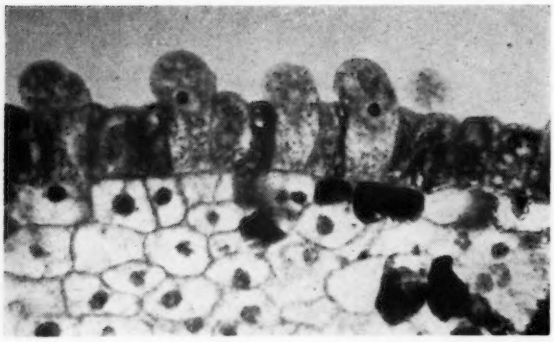

FIG. 1. *Section of young cotton seed with fiber initials emerging from the epidermis (photomicrograph). (Courtesy of Lang.)*

varieties, and adverse conditions may prolong the period for all cottons.

After the lint fibers, which are referred to in commerce as "cotton," have ceased to appear a new crop known as "fuzz" fibers emerge from adjacent cells (Figure 2C). The fuzz fibers vary in number with the variety of cotton, some strains having very few, if any, and others having a very heavy coat. The fuzz fibers and the broken lint fibers left from the first ginning are removed by additional ginning and are known in commerce as cotton "linters." Hereafter in this paper only the lint fibers known as "cotton" will be considered.

Fiber Growth

Cotton fibers grow in length for several days after they appear (Anderson and Kerr [1]). They grow slowly for the first 2 to 5 days, then more rapidly for the following 8 to 10 days, and then again more slowly, until at about 16 to 20 days fiber-length development ceases (Figure 3).

The rate of growth is determined by the variety of cotton and the environment under which it grows. A short-staple cotton may grow more slowly than a long-staple variety and vice versa. Short-staple fiber, however, usually reaches its full length in fewer days than fiber of a long-staple variety. When the fiber first emerges the seed is very small—about a millimeter in diameter. There may be 15,000 to 20,000 fibers on a seed. The fiber initials, therefore, are exceedingly small in diameter. The average diameter of the fiber at maturity is much greater than that of the initial when it first emerges. Cotton fibers are reported to be club shape—that is, they increase in diameter from the base for some distance, then reach a maximum after which no changes occur for another interval, and then taper to a relatively small tip. Just how the fiber grows in diameter and length is not yet known. The primary wall is very similar in structure and in many other properties to that of ordinary parenchyma cells. It is possible that primary walls grow more or less throughout their full length, as do parenchyma cells [14].

While the fiber is growing in length it consists of a very thin membrane which covers the protoplasm. The cell wall at this stage is 0.5 micron or less in thickness [18]. As it approaches full length the secondary thickening is deposited from the protoplasm onto the inner surface of the primary wall—that is, within the fiber lumen.

As the cell wall thickens, there appear to be zones, or regions, which are differentiated and in each of which the fine structure is different. The first layer or zone of the secondary thickening is similar in many respects to the primary wall, and the two influence dyeing and finishing. The first zone shrinks in all directions when dried and swells similarly when rewetted.

The second zone is usually referred to as the central region of the cell wall [20]. It makes up the

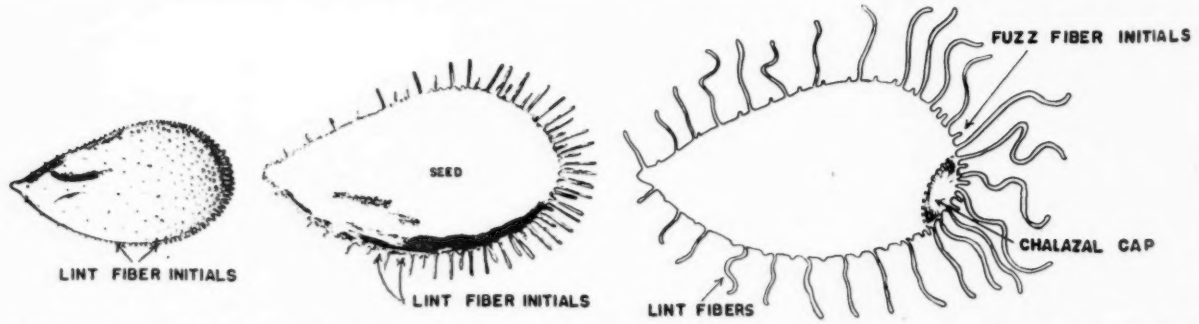

FIG. 2. *Diagrams of young cotton seeds. Left to right: A—On day of bloom, with lint fiber initials on broad end of seed; B—Two days later, with lint fibers growing out and new initials, particularly near the pointed end; C—Four or more days later, with fuzz-fiber initials among the longer lint fibers.*

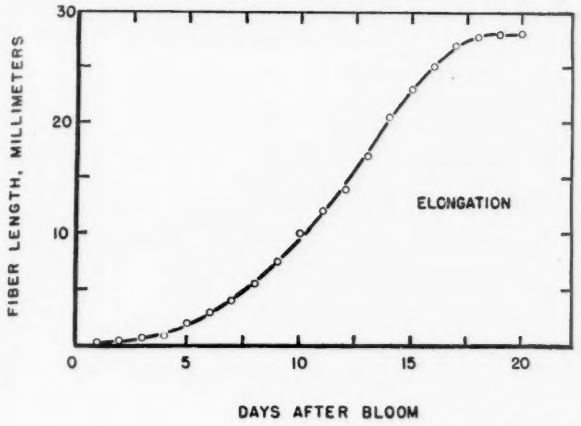

FIG. 3. *Growth in length of cotton fibers in millimeters with age of fiber in days. (Adapted from Anderson and Kerr.)*

bulk of the fiber and is responsible for tensile strength and certain other physical properties.

Levine [23] reported a fourth zone or layer adjacent to the lumen which was similar in structure to that of the outer layer of the secondary wall. Herzog and Berkley [13] observed a layer adjacent to the lumen in many cotton fibers which in unpurified cottons showed the same chemical reactions in the acetylation process as did the outer layers—that is, the primary wall and the first layers of the secondary thickening. This inner layer frequently did not acetylate even in purified linters (Figure 4), and, together with the residue of the protoplasm, contributed to the so-called "haze" of cellulose acetate solutions.

The fully matured cotton fibers, therefore, would appear to contain five distinct parts: (1) primary wall, (2) an outer layer, (3) central region of many layers, and (4) the inner layer of the secondary wall, and (5) the lumen with the residue of the protoplasm (Figure 5). It is possible that more than one layer may exist in the primary wall and in the outer and inner layers of the secondary wall in some cottons, although they have not as yet been demonstrated.

Fine Structure of the Cell Wall

In the primary-wall stage the cell membrane has the same general appearance under the microscope as a cellophane sheet. It is without striations or a visible structure except for the granular protoplasm within the lumen (Figure 6). If this membrane is stained with certain dyes the organized cellulose absorbs the dye and irregular striations become visible from the dichroism (Figure 7). The irregularity of these striations could be interpreted to mean that the primary cell wall has expanded in randomly dispersed areas throughout, rather than in a uniform pattern as would be expected if it grew at one central point. X-ray diffraction patterns of the primary wall show no crystalline cellulose until other constituents are removed by purification [6].

The first layer of the secondary thickening was designated the "winding" by Hock, Ramsay, and Harris [15]. The fibrils can be observed in this layer to spiral around the cell, with frequent reversals at irregular intervals (Figure 8). Rollins [27] had difficulty in distinguishing this layer from the primary wall. However, Kerr [19] found that it was distinct although it had many characteristics of the primary wall. It is agreed by all that it differs from the central region of the fiber, and Rollins designated the primary wall and the outer layer of the secondary thickening combined as the "fiber sheath," which admirably describes their function in cotton as it is used

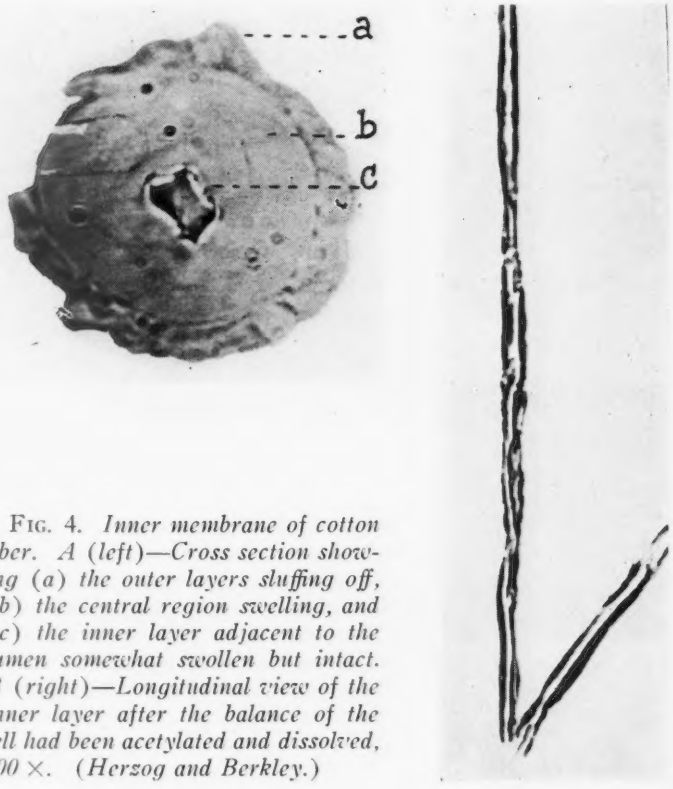

FIG. 4. *Inner membrane of cotton fiber. A (left)—Cross section showing (a) the outer layers sluffing off, (b) the central region swelling, and (c) the inner layer adjacent to the lumen somewhat swollen but intact. B (right)—Longitudinal view of the inner layer after the balance of the cell had been acetylated and dissolved, 500 ×. (Herzog and Berkley.)*

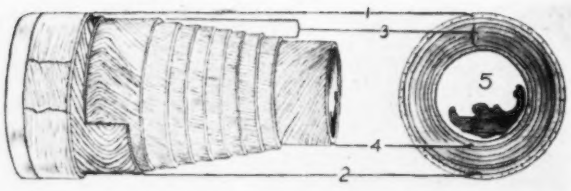

FIG. 5. *Diagram of telescoped longitudinal section and cross section of cotton fiber showing (1) primary wall, (2) first layer, (3) central region with many layers, (4) inner layer of secondary wall, and (5) lumen with residue of protoplasm.*

in commerce. In many ways the structure of these two outer layers is similar to that of regenerated cellulose in rayon, which is reported to have a netlike structure (Figure 9). So far as can be determined, cellulose of this type swells and shrinks in all directions with changes in moisture content, and the primary wall in particular shows little organized structure under the microscope except when stained.

The fine structure of the layers designated as the central region of the cell wall are finer in texture and the fibrils lie more nearly parallel with the long axis of the fiber than do those of the primary wall or the first layer of the secondary thickening (Figure 10). The long fibrils in the central region appear to lie perpendicular to the crystalline strands of the first layer of the secondary wall and at a rather large angle to such crystalline cellulose as exists in the primary wall (Figure 11).

The best information available indicates that the crystalline phase of cellulose in the central region of cotton fibers, and perhaps all natural cellulose fibers, consists of very long threadlike units, designated as crystallites, which appear to be as long as, or even longer than, the molecules themselves. It is

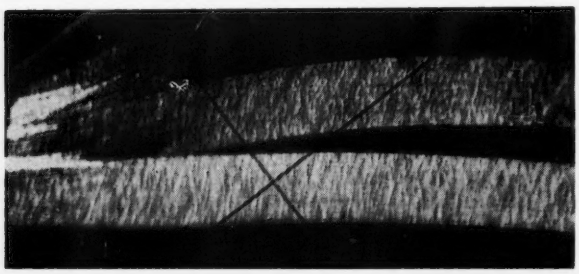

FIG. 7. *Striations brought out by the dichroism of dyed primary walls of cotton fibers (photomicrograph). Note the irregularity in pitch of the cellulose strands. (Courtesy of Kerr.)*

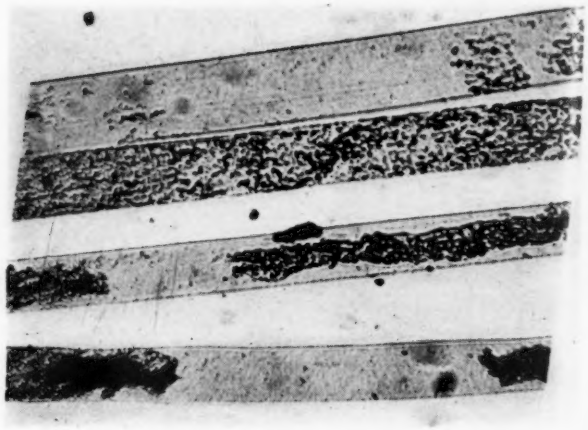

FIG. 6. *Primary wall of cotton fiber showing transparent, cellophane-like appearance. The granular material is the residue of the dead protoplasm (photomicrograph).*

entirely possible that the bundles of crystallites referred to as fibrils extend at least from one spiral reversal to another, and certain of them may continue from one end of the fiber to the other. The central region of the cell swells and shrinks with changes in moisture content, particularly in the direction perpendicular to the long axis of the fibrils. The fine crystallites appear to be bound together with noncrystallized molecules of cellulose into fibrils (Figure 12). The exact sizes of the fibrils and the minute crystallites are not known and it is quite likely that they vary in size from one type of fiber to another or even within the same fiber [7]. In certain fibers other constituents such as lignin, pectic substances, pentosans, and the like are dispersed in the cell wall and water may enter them when the fiber is wet [2]. In cotton, the noncellulosic constituents consist primarily of wax and pectic substances which appear to be confined more or less to the primary

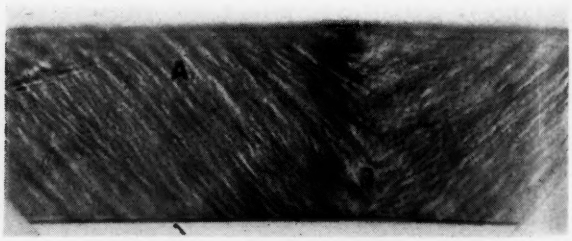

FIG. 8. *First layer of the secondary thickening, with (A) fibrils and (B) spiral reversal (photomicrograph). (Courtesy of Anderson and Kerr.)*

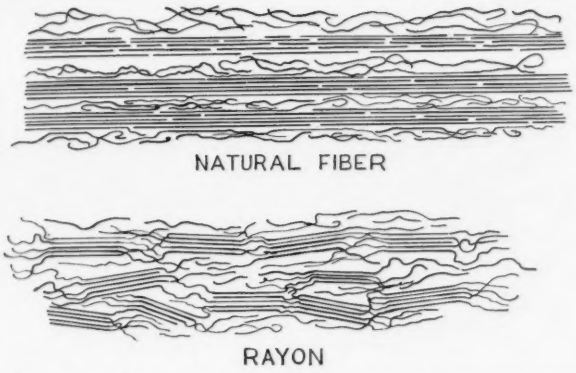

FIG. 9. *Diagram of long, threadlike fibrils indicated from physical properties of natural fibers and netlike structure reported for rayons.*

wall, and to the outer layer and perhaps the inner layer of the secondary thickening.

Convolutions and Crimp

Fiber shape may be as important in manufacturing and in the use value of a cotton as its internal structure. Cotton is recognized as one of the easiest to spin of all the known textile fibers. The natural crimp in the fiber has much to do with this ease of handling.

It was stated earlier that cotton fibers grow in length and then thicken from the interior so that the outer dimensions do not change until the outer portions mature and shrink from dehydration. In the Asiatic-type cottons the fibers average about 20 to 25 microns in diameter and have an average length of 0.5 to 1.0 inch (Figure 13A). Individual fibers, however, may be 1½ inches long, or longer. In American Upland strains the diameter is somewhat less—

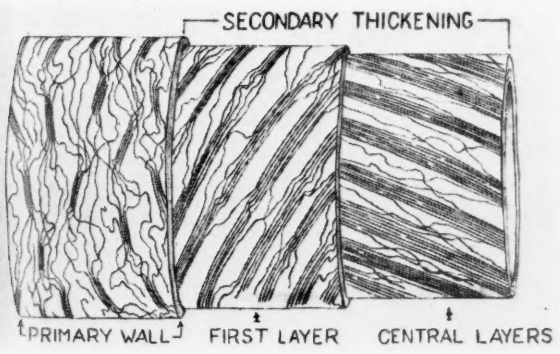

FIG. 11. *Diagram of netlike structure in primary wall and intermediate net and fibril structure in the first layer of the secondary thickening, and long, threadlike fibrils in the central region of the secondary thickening.*

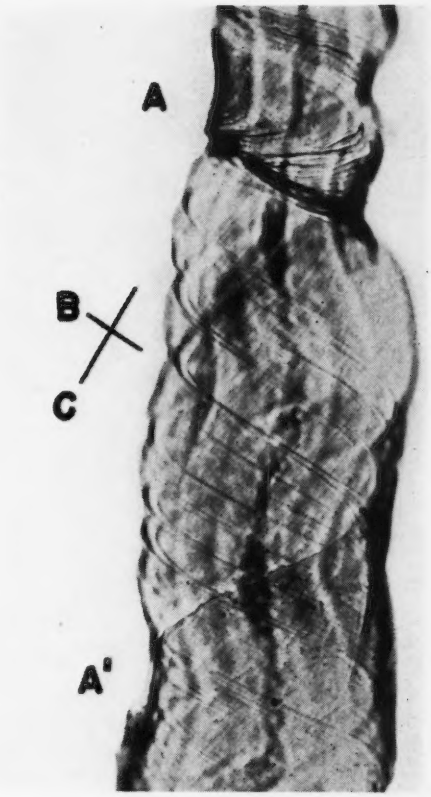

FIG. 10. *Mature cotton fiber swollen in cuprammonia. A and A'—Primary wall, stained with ruthenium red. B—Direction of cellulose orientation in first layer of the secondary thickening. C—Fibrils of the central layer of the secondary thickening. 750 ×. (Courtesy of Kerr.)*

15 to 20 microns—and the length is from 0.75 to 1.5 inches, with individual fibers even longer (Figure 13B). In Sea Island strains the diameter is still less—as low as 10 to 12 microns for the longest fiber—and the length may reach 3.0 to 3.5 inches in individual fibers (Figure 13C). The staple length of the longest Sea Island varieties may be as great as 2.5 inches and in extreme cases a fully grown fiber may be 6,000 or more times as long as it is broad. Dif-

FIG. 12. *Fragment of fibril of cotton fiber showing fine strands or crystallites, by electron microscope. The width of this fragment at the widest point is about that observed for so-called "fibrils" as seen in the light microscope.*

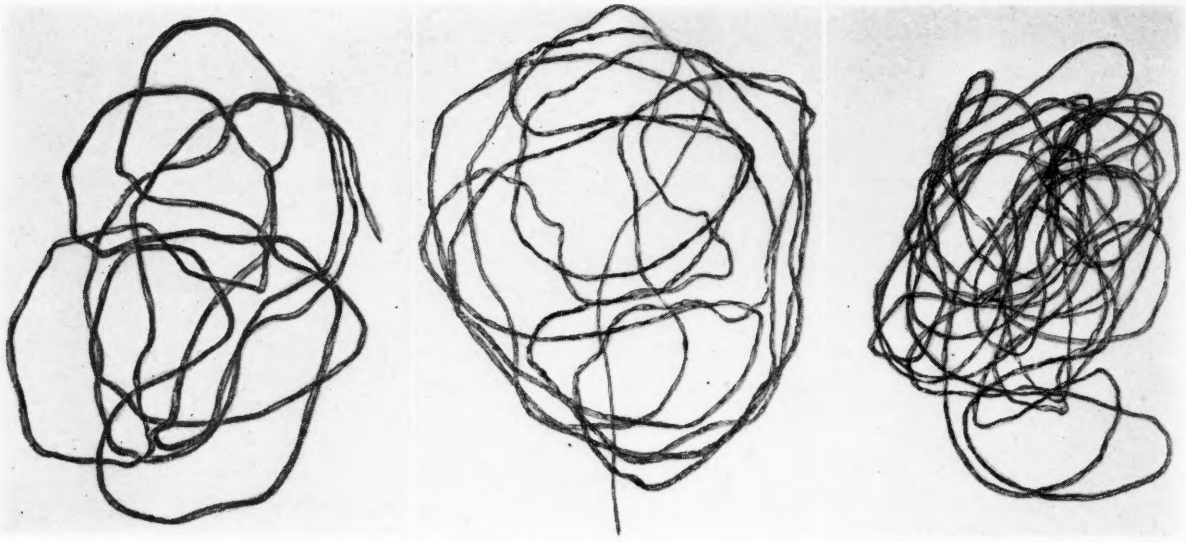

FIG. 13. *Single fibers of different types of cotton illustrating relationship of breadth to length. Left to right: A—Asiatic; B—American Upland; C—Sea Island.*

ferences in diameter can best be observed in cross sections (Figure 14). Examination of a yarn shows clearly that the finer the fiber the greater the number that can be packed into a yarn of a given size.

As the fiber grows in length it does not grow in a straight line; instead, it is crimped by folding back and forth in the boll (Figure 15). Certain of these bends are gradual; others are very sharp (Figure 16). At the point of bend the outer wall is longer than the inner wall in relation to the bend (Figure 17). The cellulose in the secondary wall is deposited while the fiber is bent or crimped. The spiral fibrils appear to be interrupted by the sharp bends in the fiber, causing reversals. It would appear from the data now available that the position of the spiral reversals might be related to the curvature of the fiber. Where the fiber is relatively straight there are few reversals. Where it is bent sharply there may be more reversals. If there are in effect two bends, one followed by a short segment of relatively straight fiber and then a second right angle bend, as in certain fibers shown in Figures 16 and 17, several reversals may occur close together.

In the green boll, while the fibers are growing

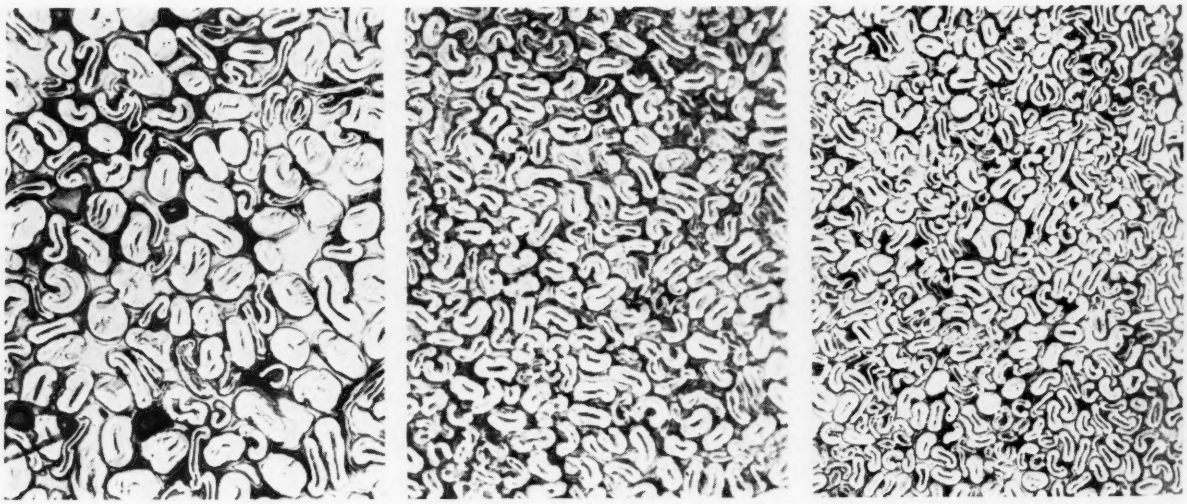

FIG. 14. *Cross sections of the three types of fibers illustrated in Figure 13. A—Asiatic. B—Upland. C—Sea Island. (Photomicrographs prepared by T. L. W. Bailey, Jr.)*

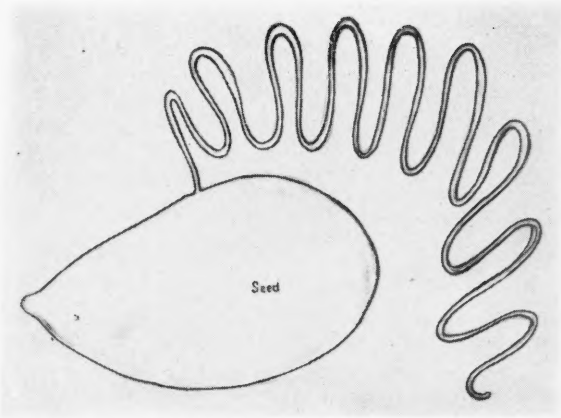

FIG. 15. *Diagram of folded cotton fibers as they grow in the boll. The fibers straighten out somewhat upon drying but retain a natural crimp.*

FIG. 16. *Tuft of cotton from unopened boll showing variations in natural crimp of fibers as they are packed around the seed.* 9 ×.

they are cylindrical, but as a fiber dries the cylinder tends to collapse into a flat ribbon (Figure 18). The shape of the ribbon depends on the thickness of the cell wall. If the cell wall is very thin the ribbon is very flat, whereas a very thick-walled fiber will collapse little if any.

The shrinkage which accompanies drying occurs between the molecules, the crystallites, and the fibrils which spiral around the cell. This creates tension diagonal to the long axis of the fiber. To some extent, the tension is released by a twisting of the fibers. These auger-like twists are known as "convolutions." The convolution interval, or number of turns per inch, is dependent upon several factors, one being the degree of thickening of the cell wall. Very thin-walled fibers—that is, fibers with primary wall only or with only a few layers of secondary thickening—do not convolute until swollen in strong caustic (Figure 18). Similarly, very thick-walled fibers convolute little if any since they do not collapse. The greatest number of convolutions,

FIG. 17. *Sharp bends in cotton fibers as they grow in the boll (photomicrograph).*

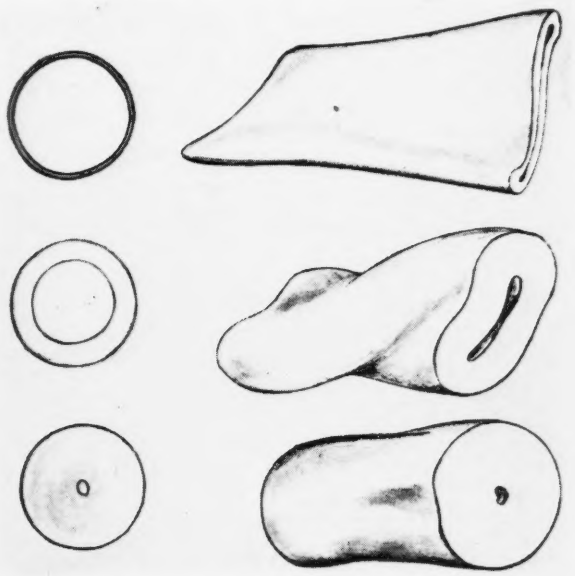

FIG. 18. *Diagram of cross section of fibers before drying and longitudinal views after drying. Note the auger-like twist (convolution) in the second fiber from the top.*

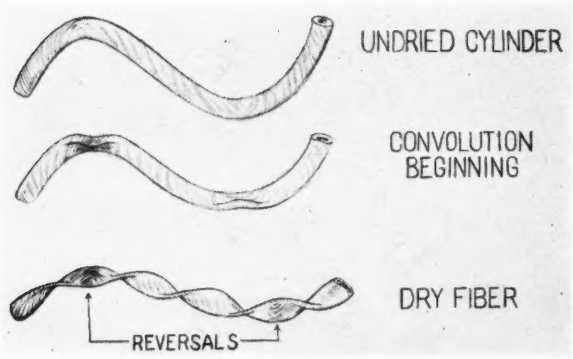

FIG. 19. *Diagram of cotton fiber before, during, and after drying. Note the reversals in the direction of spiral of both the fibrils and the convolutions. Reversals also occur at other points than the bends.*

therefore, occurs in cells with walls of intermediate thickness. All cells with a spiral structure tend to twist upon drying if isolated one from another. Most plant cells twist in one direction only, since there are no spiral reversals. Cotton cells differ from other cells by twisting in one direction along one part of the fiber and in the opposite direction in another segment; that is, the convolutions reverse at the spiral reversals (Figure 19).

By observing undried fibers under a microscope it is found that at the point of the sharp bends the longer or outer wall tends to fold itself around the shorter or inner wall. (See Figures 17 and 19.) This tends to straighten out the natural crimp of the fibers to some extent, thus giving a more linear member. The convolutions also form a spring-like structure which prevents tearing of the shorter wall at the sharp bends when tension is applied. Except

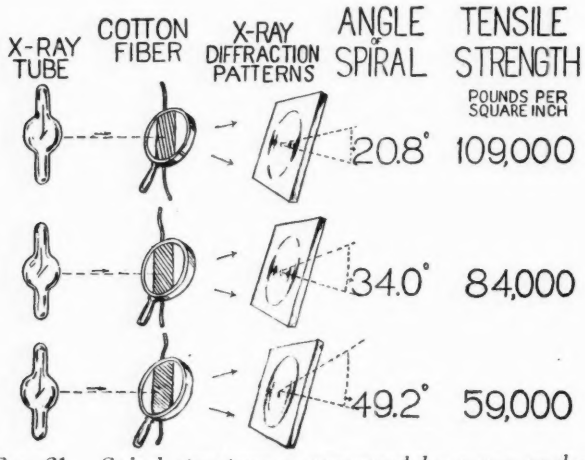

FIG. 21. *Spiral structure as measured by x-ray angles and tensile strength of cotton fibers.*

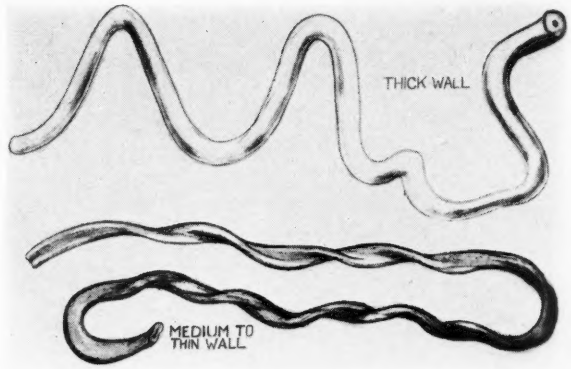

FIG. 20. *Diagram of crimped thick-wall cotton fiber and convoluted fiber of intermediate cell-wall thickness. The crimp and the number of convolutions per inch will vary with moisture content.*

for fibers with extremely thin walls, cotton consists of crimped, convoluted fibers with considerable surface friction, or highly crimped, nonconvoluted fibers that tend to felt like wool (Figure 20). Certain Asiatic and South American cottons are of the latter type. In addition to the convolutions and the crimp, the fiber surface tends to become checked somewhat, particularly if it is dried repeatedly or at high temperatures, thus adding to the surface friction of the fiber.

Structure and Strength

There is probably no other cellulose textile fiber that offers the variety of physical properties which are found in cotton. The tensile strength varies from about 50,000 pounds or less to well over 110,000 pounds per square inch. The best cottons are, therefore, among the strongest, and the poorest are among the weakest of the natural cellulose fibers.

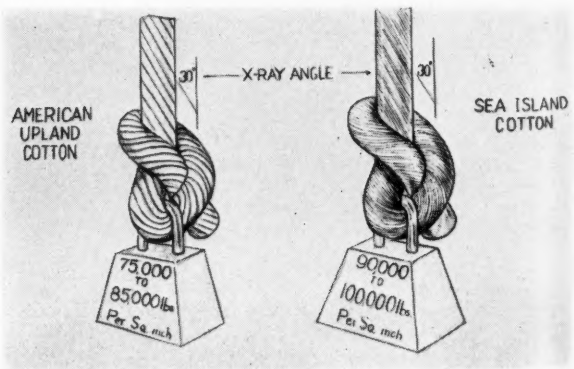

FIG. 22. *Diagram of coarse-texture upland and fine-texture Sea Island cotton, with similar x-ray angles but with widely different fiber strengths.*

Similarly, the versatility of cotton has no parallel in either the natural or the synthetic fibers. Cotton has been found to excel in more types of consumer goods than all of the other textile fibers combined.

There have been numerous studies to determine the causal factors in the tensile strength of this unusual fiber. In these studies microscopic and x-ray methods have been used to measure the pitch of the cellulose spiral in the cell wall. For cottons in general there is a relatively high correlation between the spiral structure of the crystallites in the cell wall and the tensile strength, in thousands of pounds per square inch (Figure 21). An index of the angle of spiral is given by the so-called "x-ray angles."

In general, the steeper the pitch of the spiral the greater the fiber strength, and vice versa. Cottons of widely different origin, such as Sea Island and American Upland strains, however, show variations in this relationship. The Sea Island fibers are stronger than the Upland types for a given spiral structure (Figure 22). The slope of the regression lines (when strength is calculated from the structure) may also be different for the two fibers (Figure 23). The data are limited, however, and further study is needed to clarify the exact nature of these relationships. This is particularly true since, within a variety, cotton grown under certain conditions may be stronger for a given spiral structure than fiber grown on plants from the same lot of seed at another location, or even the same location in different seasons. If the weather changes abruptly during the summer, wide differences in the strength-structure relationship may be shown by fibers grown on the same plants (Figure 24). The line connecting the points representing the x-ray angles and that representing the Pressley strength in-

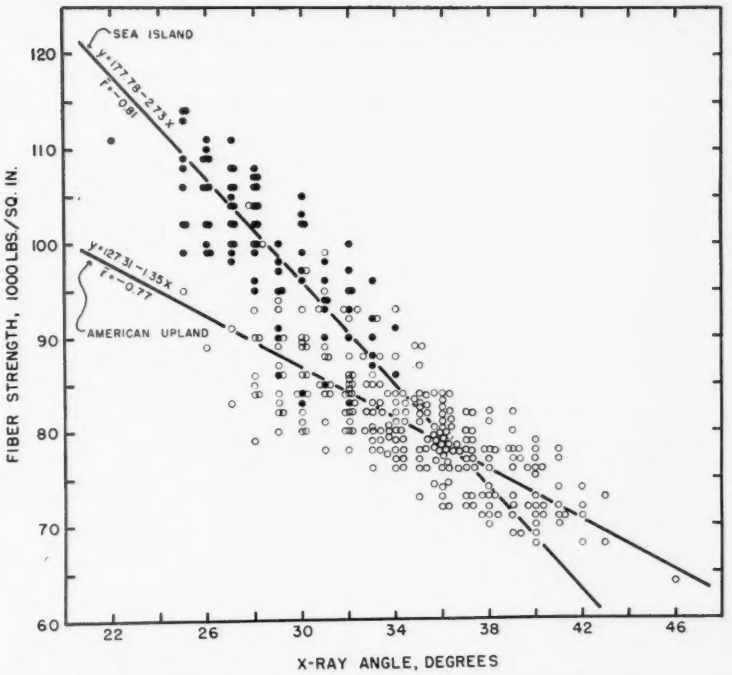

FIG. 23. *Tensile strength and spiral structure as shown by x-ray angles of Sea Island cottons (shaded circles) and American Upland cottons (open circles). Regression equations and r̄ values are given for each group separately.*

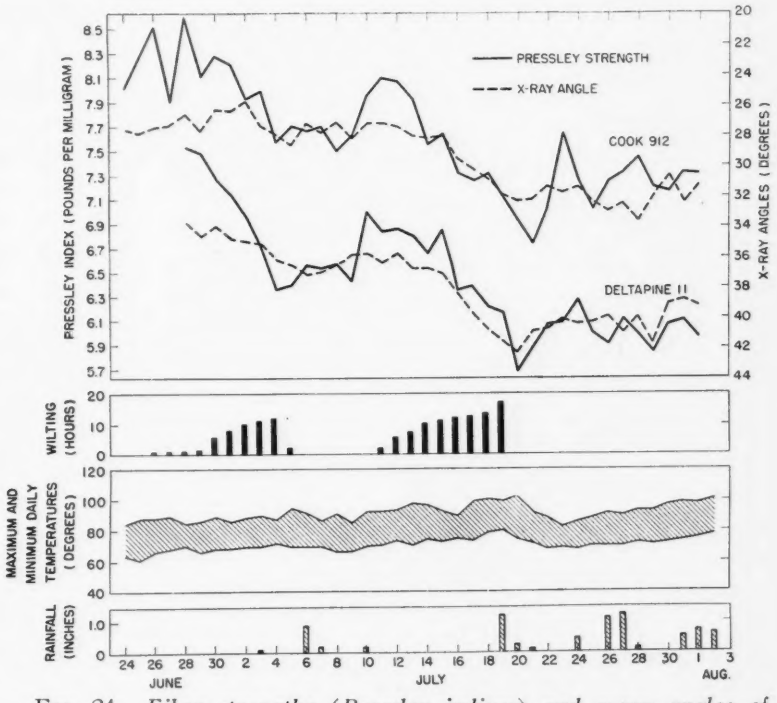

FIG. 24. *Fiber strengths (Pressley indices) and x-ray angles of cotton fiber, daily wilting of cotton plants; temperature range for day and night, and rainfall during period of deposition of secondary thickening of the fibers tested. Certain fibers were much stronger, others weaker than was expected from x-ray angles. (Kerr and Berkley.)*

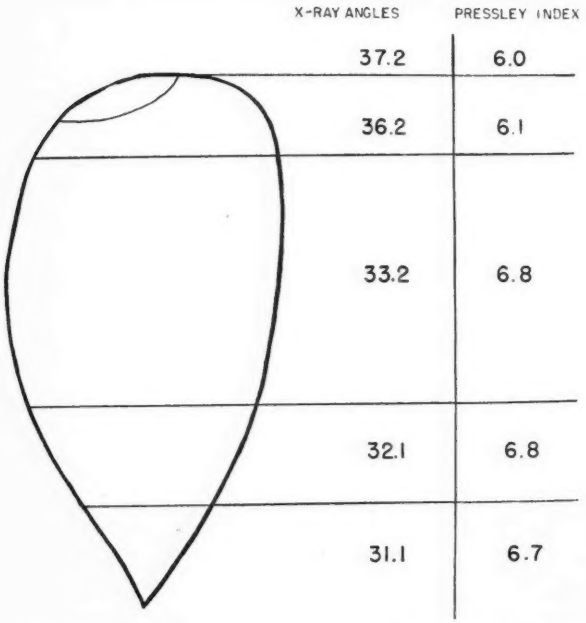

FIG. 25. *Outline of cotton seed and structure and strength of fibers from the different regions of the seed, as indicated.*

dices are roughly parallel except for the samples taken during the month of June, a period between the 10th and 16th of July, and one or two days later in July, where the strength was greater or less than expected for the x-ray angles. The reasons for these wide variations particularly in the structure-strength relationship are not yet known, but it would appear that in general the same type of structure differences can be produced by environment as is common between species.

There are at least five possible explanations for these differences: (1) length of cellulose molecules—that is, degree of polymerization; (2) texture of the fiber—that is, size of crystalline units and perhaps fibrils; (3) ratio of crystalline to noncrystalline material—that is, degree of order; (4) density, or apparent specific gravity of the fiber; and (5) chemical makeup of the cell wall. Unfortunately the methods for measuring these properties are either slow and impractical or not accurate enough to permit comparisons of the large number of samples required to establish fundamental relationships.

Cellulose degradation that tends to reduce the degree of polymerization (D.P.) or length of the molecule also reduces the strength for a given cotton; therefore, where marked degradation has resulted in bleaching, for example, there may be a relation between the D.P. and tensile strength. A study is being made to determine whether or not there is a relation between the D.P. and the spiral structure or the fiber strength in undamaged cottons.

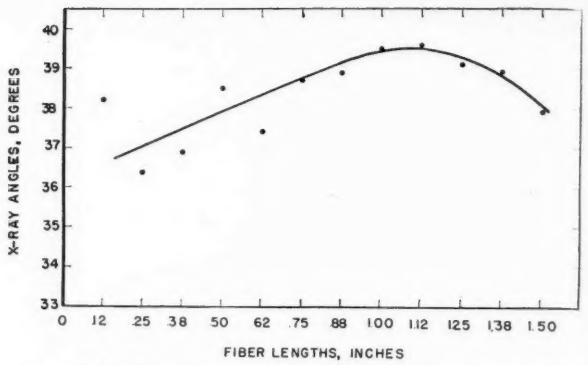

FIG. 26. *Fiber structure, and length of cotton removed from the seeds with a Pressley fiber sorter. (Line fit by sight.)*

Differences in texture probably would be closely associated with apparent specific gravity and perhaps also with degree of order. In general, it appears that fibers with relatively long boll periods for a given cell-wall thickness are stronger than those with short boll periods for a given x-ray angle. This is interpreted to mean that the finer the texture the stronger the fiber for a given spiral.

Variations in cotton fiber properties within a given variety and even within a given sample are important to breeders as well as to manufacturers. If fibers are carefully removed from the seed by hand they show an increase in spiral structure, x-ray angle, from the tip (micropylar end) to the blunt end (chalazal cap) of the seed (Figure 25). Fiber length and fineness also increase from the tip to the chalazal cap. The changes in fineness (weight per inch) may be attributed in part to changes in cell-wall thickness. The fibers on the chalazal cap have very thin walls.

There are also differences in fiber structure and strength at different positions in the boll. The x-ray angles increase and the strengths decrease from

TABLE I. FIBER LENGTHS (SUTER-WEBB SORTER), X-RAY ANGLES, AND PRESSLEY INDICES FOR A SAMPLE OF COTTON GINNED ON A COMMERCIAL-TYPE SAW GIN

Fiber length	X-ray angles	Pressley index
$\frac{1}{4}$ to $\frac{5}{8}$ in.	35.2	5.73
$\frac{3}{4}$ to $\frac{15}{16}$ in.	33.9	6.76
1 to $1\frac{5}{16}$ in.	33.4	7.11

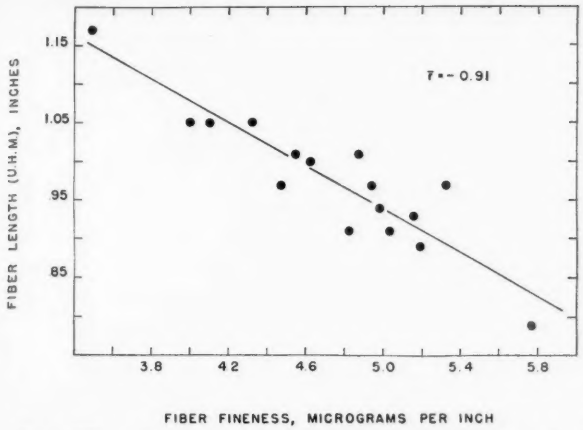

FIG. 27. *Average fiber length and weight per inch for 16 varieties of cotton grown at 8 locations, 1935–1937 inclusive, showing a positive relationship between length and fineness. The lower the weight the finer the cotton. (Regression line is given.)*

the base to the tip of the boll. For instance, in a boll taken from the same sample as that used in Figure 25, the variations were as follows:

	X-ray angles	Pressley indices
Tip	35.8	6.1
Middle	34.3	6.4
Base	33.9	6.7

Many bolls show little or no variation from base to tip. Cotton breeders strive to reduce by selection all

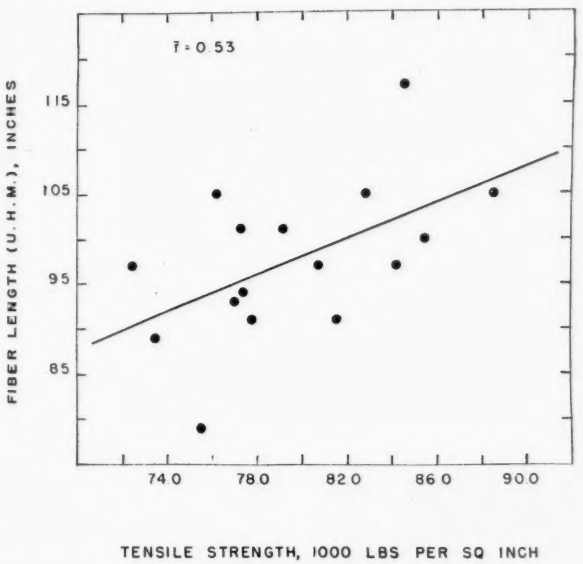

FIG. 29. *Fiber lengths and strengths illustrating positive relationship for variety effect for 16 varieties of cotton grown at 8 locations during 1935–1937 inclusive. (Regression line is given.)*

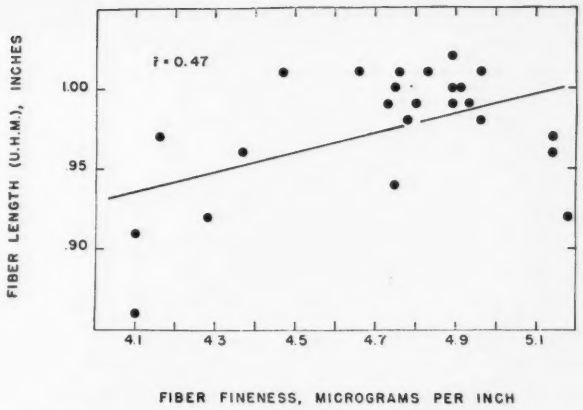

FIG. 28. *Average fiber length and weight per inch indicating inverse relationship of fineness and length for cotton grown at 8 locations during 1935–1937 inclusive. (Regression line is given.)*

variations, particularly fiber lengths, within a variety or strain of cotton.

When seed cotton is dyed in a binary dye mixture [12], the fibers on the chalazal cap are dyed green, whereas those on the balance of the seed are, for the most part, dyed red. In general, the green fibers are weaker (by the Pressley method) than the red fibers; however, in certain cottons the reverse has been found to be true.

When the fibers are removed from the seed by a Pressley sorter the x-ray angles, in general, tend to increase with length up to about 1 to 1⅛ inches, then decline as the length becomes greater (Figure 26). If, however, fibers ginned on a commercial-type saw gin are sorted carefully on a Suter-Webb sorter the x-ray angles become smaller and the strengths greater with increased length (Table I). This is interpreted to mean that the long, weak fibers with thin walls, in the region of the chalazal cap, are broken to some extent by the Pressley sorter and particularly so by the saw gin. There is also a possibility that the bolls with longer fiber tend to have stronger fiber; thus the ginned sample, being a mixture of many bolls, shows the natural tendency of fiber structure, strength, and length all to be genetically associated.

The finite relationships between fiber properties have not yet been established. By and large for varieties of American Upland cottons, the longer the fiber the lower its weight per inch and vice versa (Figure 27). If, however, cotton varieties are grown under widely different conditions, the fiber weight tends to increase with increased length (Figure 28).

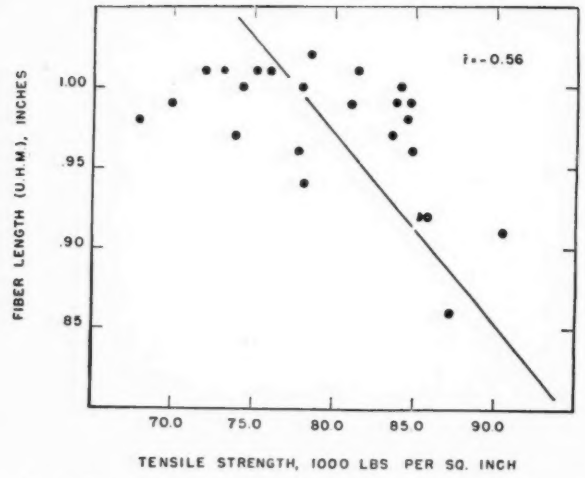

FIG. 30. *Fiber length and strength indicating inverse relationship for location effects for 16 varieties of cotton grown at 8 locations during 1935–1937 inclusive. (Regression line is given.)*

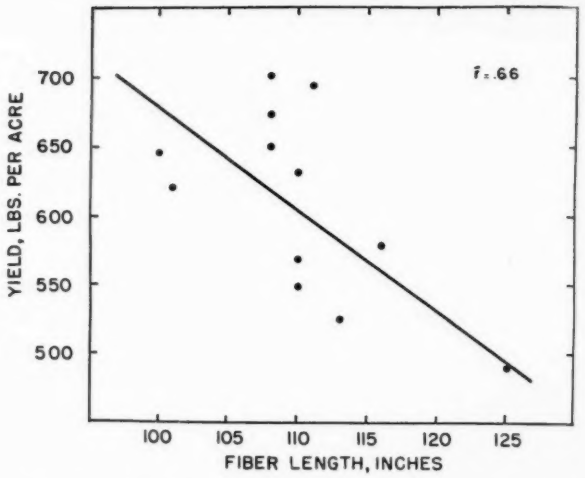

FIG. 31. *Yield of lint cotton in pounds per acre, and staple length from 12 varieties or strains of cotton grown at 7 locations in Mississippi Delta, 1944 crop. (Regression line is given.)*

Similarly, if varieties are compared, it is seen that the length and strength tend to increase together (Figure 29), whereas if environment affects the fiber properties within a variety the strength tends to decrease as the length increases (Figure 30). As will be shown later, these reversals in relationships between the various fiber properties make it difficult to interpret relationships between fiber properties and skein strengths of yarns spun from the cottons.

Unfortunately, the exact relationships of fiber properties and yield of cotton, in pounds per acre, are also yet to be determined. In general, when varieties are compared a trend is observed for the yield of cotton to go down as fiber length increases (Figure 31 [24]). If, however, cottons are grown under different conditions, the factors that tend to reduce length also reduce yield and vice versa, so that a positive relationship may be expected between fiber length and yield when conditions of growth are compared.

Changes in Cotton Fibers upon Swelling under Tension

The physical properties of cotton fibers, being dependent on cell-wall structure, can be modified. Undried cotton fibers are plastic and can be readily modified by stretching [9]. The changes in strength are roughly proportional to the changes in structure. If a maximum tension is applied, all fibers tend to flow to about the same end point, as measured by the x-ray angles, irrespective of the original structure.

The rate and the temperature of drying cotton fibers also affect their properties. Fibers removed from bolls at 40 to 45 days after bloom were dried (1) in the laboratory without additional heat and designated air dry, (2) in an oven at 100°C, (3) in an oven at 125°C, (4) in an oven at 150°C, and (5) in a blast of hot air. In the last experiment the fibers were held in the hands or in a small sieve so that they were not confined. The hot air discolored the fibers immediately, whereas the other treatments were more gradual in their effects. A second series was treated at 15 pounds steam pressure prior to drying.

The fiber strengths (Pressley method) for the two series were approximately the same. The samples subjected to steam before drying, and the steam-

TABLE II. FIBER STRENGTHS OF COTTON TAKEN FROM BOLLS 40 TO 45 DAYS OLD AND DRIED AT VARIOUS TEMPERATURES (1) WITHOUT FURTHER TREATMENT AND (2) AFTER AUTOCLAVING AT 15 POUNDS STEAM PRESSURE (PRESSLEY INDEX, POUNDS PER MILLIGRAM)

	Air-dried		Oven-dried		Hot-air blast
	Room temp.	100°C	125°C	150°C	100°C or more
Untreated*	5.78	5.72	5.75	5.72	5.51
Treated†	5.79	6.04	5.96	5.77	5.59
Mean	5.79	5.87	5.86	5.74	5.54

* Bolls opened only.

† Bolls opened and treated at 15 pounds steam pressure before drying.

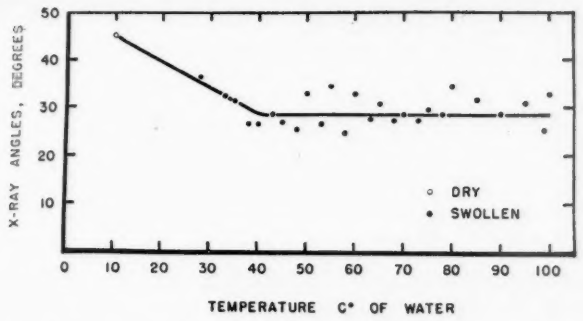

FIG. 32. *Changes in spiral structure of cotton fibers swollen in water at different temperatures while under tension. (Line fit by eye.)*

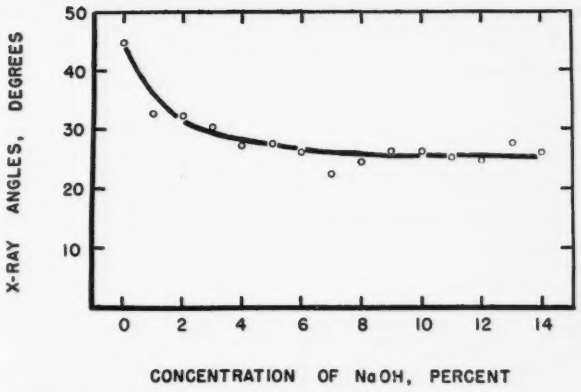

FIG. 33. *Changes in spiral structure of cotton fibers treated under tension with increasing concentrations of caustic. (Line fit by eye.)*

treated samples which were oven-dried at 100°C and 125°C were somewhat stronger than the air-dried or those dried at 150°C, although these differences were not statistically significant (Table II). In both the steamed and unsteamed samples the fibers dried in a blast of hot air were weakest. There was less opportunity for control in this group; hence it is not known whether or not the damage was due to the higher temperatures or to the speed of drying.

Field damage will change the fiber structure-strength relationship, particularly if biological decay sets in. Samples of cotton inoculated with cellulose-destroying fungi will lose strength rapidly but the x-ray angles change little, if any, until all the strength is lost (Table III).

Ultimately, if decay is unchecked, the typical cellulose diffraction pattern can no longer be clearly identified in the amorphous halo produced from the disintegrating cell walls.

Ordinary dry cotton as found in commerce may be modified by swelling the fibers while they are held under tension. The spiral structure changes when the fiber is swollen in water at room temperature and stretched (Figure 32). At a given tension the amount of flow increases as the temperature is increased up to about 50°C, after which no consistent change is noted.

If cotton is swollen in NaOH or any swelling agent it will stretch under strain. The amount of stretch for a given load increases with the concentration of caustic—rapidly at first, then more slowly (Figure 33). In general, the strength is increased as the x-ray angles are decreased. When fibers are swollen and stretched in strong caustic, the increase in strength is not so great per degree of change in structure as when they are swollen in water. Caustic of mercerizing strength may permit more flow than weaker caustics if the tension is maintained for a long period or is increased.

TABLE III. STRUCTURE AND STRENGTH OF COTTON (STONEVILLE 5) FIBER BEFORE AND AFTER ATTACK BY FUNGI UNDER CONTROLLED CONDITIONS (HUMFELD AND BERKLEY)

Condition	X-ray angle (degrees)	Fiber strength (1,000 lbs./sq. in.)
Control	36	84
Sterilized incubated	36	76
Not sterilized incubated	36	68
Sterilized inoculated & incubated 1 wk.	36	64
Sterilized inoculated & incubated 2 wks.	37	60
Sterilized inoculated & incubated 3 wks.	36	52
Sterilized inoculated & incubated 4 wks.	37	57

Spinning Quality of Cottons

Fiber properties, used by breeders in determining the mode of inheritance of high quality in cotton, are also useful to the manufacturer and to the consumer as a means of differentiating between cottons. To a limited degree, the better cottons can be recognized on the basis of their fiber and spinning properties but a more nearly perfect differentiation could be made: (1) if the limits of the spinning technique were revealed; (2) if sufficient duplication of samples were used on key varieties at a number of locations to give a good error term to be used in establishing significance between cottons; and (3) if fiber standards were used to keep the methods in

all laboratories on the same level so that comparisons could be made from one to the other.

For many years attempts have been made to determine the contributing factors in spinning quality. Turner [29] came to the conclusion that fiber strength is of little value in making predictions of the skein strength of singles yarn because too little of the fiber strength is realized in the yarn. Köhler [21] reviewed the early work on spinning and stated that only 10 to 20 percent of the fiber strength is evident in the yarn strength. Turner and Venkataraman [30] correlated certain fiber properties with yarn strength and concluded that fiber length is most closely associated with highest standard warp count and that fiber weight per inch is next in order. The correlations of ribbon width and number of convolutions per inch were doubtfully significant, whereas those of fiber strength and rigidity were nonsignificant. Kapadia [17] came to the conclusion that fiber fineness is more important than fiber length and that the fiber strength is a major factor in estimating the value of a cotton. Hutchinson and Govande [16] obtained, by separating varietal and environmental factors, relatively high $\bar{r}$ values for variety effects and low $\bar{r}$ values for environmental effects when they correlated mean fiber length and fineness with spinning value of Indian cottons. Richardson [26] found that greater fiber length, lighter unit weight (greater fineness), and higher intrinsic fiber strength singly and collectively lead to a greater elasticity and strength in yarns, and suggested that more uniformity in all properties would lead to better cottons. Underwood [31] found that spinning quality is related to a greater effective length, percentage of normal (thick-walled) hairs, and a lower mean hair weight per centimeter, in the order given. In this study the American-type cottons grown in the British Empire, were similar in the over-all relationships to other types, including Egyptian cottons. Where the Egyptian cottons were examined alone, however, length was not significantly correlated with spinning quality.

Webb and Richardson [32, 33] made a general or over-all correlation of fiber properties and skein strengths, using (1) upper quartile fiber length, (2) Chandler bundle strengths, (3) weight fineness, (4) grade of cottons, (5) length uniformity, and (6) percent thick-walled fibers from the regional variety data of 1935–1937, and later by substituting fiber length from the fibrograph and Pressley strengths for the upper-quartile fiber length and the Chandler strength, respectively. The correlations obtained are excellent as far as they go and will be of considerable importance to cotton people in general. Their work, like that of the early English and Indian studies, before variance analysis was commonly used, are representative of the pooled effects of variety and environment and do not give all the information desired.

Webb and Richardson found in the first study that "in terms of skein strength of 22s and 60s carded yarn, fiber strength was the most important of the six fiber properties considered; it was followed in turn by coefficient-of-length variability, upper-quartile length, fineness expressed as weight per inch of fiber, grade of cotton, and percent of mature fibers."

In the second study there were slight changes in the order of significance for 22s. The order of the fiber properties was: (1) fiber strength (Pressley method), (2) upper-half mean fiber length (fibrograph), (3) uniformity ratio, (4) grade of cotton, (5) fiber fineness (weight per inch), and (6) percent of mature fibers. For 60s yarn, fiber fineness was more important than grade of cotton.

Smith [28] also examined the regional variety data for 1935–1937, inclusive, using variance analysis, and found that about 68 percent of the variations in yarn strengths were explained by five fiber properties: (1) fiber length (25-percent point), (2) fiber strength (Chandler bundle method), (3) fiber fineness (weight per inch), (4) percentage of thin-walled fibers, and (5) coefficient-of-length distribution. The total or over-all correlation was, of course, the same as that of Webb and Richardson, except for grade of cotton, which Smith did not use.

For the within-variety—that is, the environmental—effects, Smith found the following order of significance, in terms of variability accounted for: (1) fiber strength, (2) fiber-length uniformity, (3) percent of thin-walled fibers, (4) fiber fineness, and (5) fiber length. The order of the percent of thin-walled fibers and fiber length changed places in order from that of the over-all correlation.

When varieties within locations were compared, Smith found: (1) fiber length to be most important, with (2) fiber strength, (3) fiber fineness, (4) fiber length uniformity, and (5) percentage of thin-walled fibers following in the order given. This changed the order of significance completely, and since

length uniformity dropped to fourth position and became insignificant, it would appear that some environmental factor or the ginning process had affected it.

Barker [4], using mixed lots of samples from an unbalanced experiment for only one year, developed a number of formulas for predicting skein strengths of 22s and 36s yarn, based on the varietal and the environmental effects and the total or over-all relationships. The data were limited and grade of cotton was not taken into account. For the over-all correlation the order of importance was: (1) fiber length, (2) fiber strength, and (3) fineness. When varieties were compared, fiber strength, length, and fineness accounted for about 78 percent of the variability in skein strength of 36s yarn. Of this amount, fiber strength accounted for most, with fiber length and fineness following in turn. The exact percentages of variance attributed to each factor will vary from one set of data to another. When comparisons were made within variety at different locations, the contribution of fiber length was greatest, that of strength second, and that of fineness third.

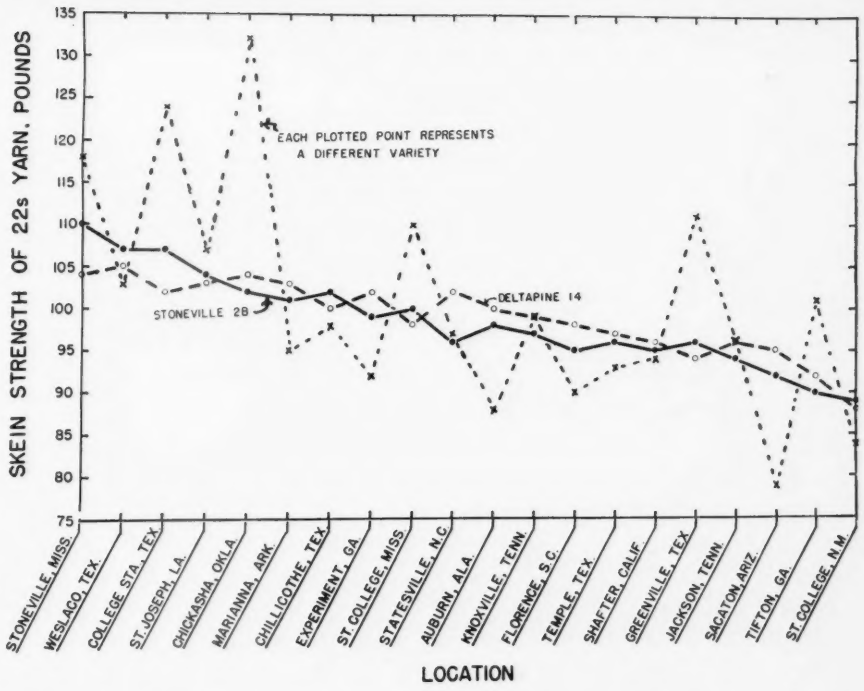

FIG. 34. *Skein strength of 22s yarn from Deltapine 14 and Stoneville 2B cottons and miscellaneous samples of many varieties of the same general grade and staple grown at 20 locations in 1943. (Lines connecting points for guidance of eye only.)*

Barker and Berkley [5] reported a means of comparing varieties in an unbalanced study when it was desirable to predict roughly how the cottons would perform in 22s and 60s carded yarn. No attempt was made to evaluate all fiber properties with respect to spinning quality. Berkley and Barker [10] observed that the importance of the various fiber properties changed when going from 22s to 60s yarn. Fiber strength appeared to be more important in 22s, whereas length, and particularly fineness, gained in importance at the expense of fiber strength at the higher counts.

Fiber fineness, in terms of weight per inch, at least, is dependent to a great extent on degree of cell-wall thickness. Cell-wall thickness varies in well-matured samples but is more pronounced in late-picked and particularly frosted cottons in the Southwest, where the plants are killed before the fiber matures. The ease of spinning and the appearance of the yarns are more affected by immaturity than are the yarn strengths [8]. Yarn strength may be increased by an increase in percent of thin-walled fibers caused by stress on the plants during growth. The appearance of a yarn may, of course, outweigh other factors in importance for special uses. The yarn-appearance grade like yarn strength, for example, is dependent on many factors, among which are fiber fineness and particularly degree of cell-wall thickness [25].

It must be borne in mind that the observations reported by Webb and Richardson, and by Smith, in particular, as well as those reported by Barker, and by Berkley and Barker to a less degree, are limited by field damage before picking and also by certain injuries to the fibers caused by the ginning, spinning, and handling of the cotton.

A more comprehensive study would clarify this picture. More care should be taken to avoid field damage, and early-, medium-, and late-picked cottons should be compared with sufficient duplication

TABLE IV. SPINNING AND FIBER PROPERTIES OF CERTAIN WIDELY GROWN OR PROMISING NEW UPLAND COTTON VARIETIES

Areas, varieties, and strains	Yarn properties		Staple estimates		Fiber properties: Length measurements				Fiber properties: Strength indices		Fiber properties: Fineness and wall development		
					Fibrograph method		Array method						
	Skein strength of 22s	Appearance grade	Classer's designation	Equivalent staple	Upper-half mean	Mean	Upper quartile	Mean	Pressley index	X-ray angle	Weight per inch	Surface area (Arealometer)	Thick-walled or "mature" fibers
	(lbs.)		(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(lb./mg.)	(degrees)	(mg.)	(cm.²/mg.)	(%)
Irrigated area:													
Acala Mesa*	156.9	C+	1.14	1.49	1.29	1.00	1.44	1.16	7.43	36	3.2	3.18	84
Acala 1517 W	137.9	B−	1.06	1.25	1.13	0.92	—	—	8.06	30	3.6	2.92	79
Acala 4–42	126.6	B	1.05	1.15	1.14	0.87	—	—	7.25	35	4.2	2.78	80
Acala P18C	105.7	B	1.02	0.97	1.07	0.84	—	—	6.36	41	4.1	2.95	79
Texas-Oklahoma area:													
Rowden 41B	99.3	B+	0.93	0.90	0.95	0.76	—	—	7.30	32	5.7	2.33	83
Hi-Bred	87.2	B+	0.84	0.79	0.81	0.66	—	—	7.35	33	5.3	2.63	75
Mebane 140	86.9	B+	0.86	0.87	0.84	0.69	—	—	7.63	31	5.4	2.41	82
Midsouth area:													
Coker 100 Staple	115.2	B+	1.08	1.06	1.17	0.90	—	—	6.31	38	3.8	3.02	75
Deltapine 14 & 15	109.8	B	1.01	1.01	1.05	0.83	—	—	6.94	37	4.4	2.86	78
Stoneville 2B	109.4	B+	1.01	1.03	1.04	0.82	—	—	7.45	32	4.1	3.06	73
Delfos 9169	111.7	B+	1.06	1.03	1.11	0.84	—	—	6.37	36	4.2	2.96	72
Southeast area:													
Wilds	136.2	C+	1.24	1.32	1.29	0.98	1.42	1.14	7.93	35	3.8	3.40	74
Sealand 542*	131.6	C+	1.37	1.22	1.38	1.06	1.44	1.06	7.98	32	3.2	3.16	71
Empire WR	108.4	B	1.01	1.00	1.05	0.82	—	—	6.96	33	4.2	3.06	70
Coker 100 Wilt	108.7	B+	1.03	1.00	1.07	0.85	—	—	6.50	37	4.2	2.91	75

NOTE: The values given are averages of all of the observations from the 1943, 1944, 1945, and 1946 annual varietal and environmental studies. Skein strengths from the 1943 and 1944 reports were adjusted to long-draft values given in later reports. (An asterisk following a variety name indicates fewer than 6 station-year observations, and hence data that may not be as reliable as for the other varieties.)

to show variability in the spinning process and to give a reliable error term for establishing significance between samples.

The industry is no doubt interested in the stability of a given variety, and how environment influences fiber properties and spinning quality as measured by skein strength. There is a great deal less variability in skein strengths of 22s yarn, for example, from a given grade and staple within a variety grown at different locations throughout the Cotton Belt than there is in cottons in general of the same grade and staple grown at the same locations (Figure 34). If it were possible to add the designation of variety and location of growth to the grade and staple of each bale of cotton, the farmer, the merchant, and the manufacturer would all gain by it.

Such a system would require, however, that all varieties, the lints of which would be labeled, be certified, since there is a tendency for most cotton varieties to break up into forms. Certain of the segregates produce shorter or weaker fiber; others produce longer or stronger fiber, and vice versa, than the original parent. Commercial cotton varieties in general act like hybrids—that is, they segregate. For most upland cottons, particularly in the boll-weevil area where a crop must be set early and relatively rapidly, for good yield a farmer should not replant his own seed over and over again.

Yields in terms of pounds of fiber and seed per acre are the first prerequisites of good variety in cotton. The location influences yield to the extent that data are made available locally by the various State Experiment Stations for adapted varieties. The fiber and spinning data on certain new varieties of cotton which either are in production or show commercial possibilities are listed in Table IV. Many new strains with excellent fiber properties are observed by cotton breeders but unless these show outstanding yields they never reach production. In Table IV, for economy of space the individual cottons are listed only in the region where they are best known. This does not mean, however, that they are not grown commercially in other regions.

Discussion

Concepts in a given science, like living beings, grow; therefore the observations made by Turner and his colleagues and also those made more recently must be considered as the foundation for an understanding of spinning quality of cotton rather than the final answers. So far, each study reported which deals with fiber properties and spinning quality, has presented a slightly different order, or combination of significant properties. This is not unnatural since cottons differ widely and different laboratories have used either different methods or different samples or both. Smith compared, by variance analysis, interlocking effects resulting from hereditary characteristics and modifications of them resulting from growth conditions, but the data were limited by differential picking, handling, and field damage of the samples in the various locations where they were grown and possibly by variations in ginning and spinning. Unfortunately, no one study has been made in which sufficient control was exercised to avoid what are now known to be obvious limitations, and so far all of the more comprehensive studies have been confined to spinning quality without regard for weaving and finishing or, what may be more important, use value.

There are also many fiber properties which have not yet been taken into consideration in the spinning-quality studies, some of which must await the development of practical methods for measuring them. It is regretted in this connection that the dyers and finishers have not as yet come up with a good method or series of methods for measuring cotton quality from the point of view of appeal to the customer. Pioneers in this phase of cotton research are badly needed. Their absence among scientists may be considered to be due to the lack of competition which cotton has had from other fibers. Competition is rapidly developing, however, not only from other fibers such as rayon and cottonized bast fibers but also from foreign-grown cotton.

Much progress has of course been made in cotton research, and conditions are rapidly improving. The time is near when a well-organized study of improved American cottons can be made, and fundamental research will prove its worth in this field as it has in other fields of science.

Acknowledgment

The author wishes to express his appreciation for the suggestions given by Dr. H. W. Barre under whose direction this work was done. Miss Mary Dooley made the measurements included in Figure 32 and Miss Bula Carlson those of Figure 33. Acknowledgment is also made to Mr. George Mars-

den, who drew the sketches for Figures 2, 5, 11, 15, 18, 19, 20, 21, and 22.

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Textile Testing in Germany*

Part III. Testing Flexural and Compressional Properties

Herbert F. Schiefer, Lyman Fourt, and Richard T. Kropf

1. Resistance to Creasing

At the time of this investigation the most general method used in Germany for measuring the resistance of fabrics to creasing or wrinkling was to cut a strip 4.5 cm. long and 1.5 cm. wide, fold one end back over the other for a distance of 1.5 cm., and place it between two glass plates under a given weight and for a given period, usually from 1 to 3 hours. The weight is then removed and the creasing angle A, which the short end of the specimen S makes with the long end, is measured with a protractor, as shown in Figure 60, after 5 minutes and again after 1 hour.

Another method used was the following. A specimen, raveled to 15 cm. long and 10 cm. wide, is placed on a flat surface. A cardboard 10 cm. wide, 3 cm. long, and 0.5 mm. thick is placed on the specimen and aligned with one end. The remaining long end is then folded over the cardboard and a second cardboard is placed directly above the first. The remaining long end is again folded back over the second cardboard. This process is repeated two more times, resulting in an accordion-type pack consisting of five layers of fabric, 3 cm. long and 10 cm. wide, with a cardboard between each layer and the next one. The pack is compressed for 1 hour by a weight of 8 kg. The weight is then removed, the cardboards are carefully removed, and the creased specimen is suspended vertically for 1 hour by one end on a frame in front of a sheet of graph paper, as shown in Figure 61. A right triangle is placed against the graph paper, and the length of the specimen is read from the graph paper. Assuming that the zigzag specimen consists of five planar sections and that the four intersecting angles formed are equal, a table is prepared from which the value of the intersecting angle can be obtained from the length of the zigzag specimen. This value is taken as a measure of the creasing angle.

The creasing angle as determined by the above methods depends, as is apparent, upon the weight of the specimen. In the latter method, A. ten Bruggencate, working at the Fiber Research Institute at Delft, found that the segments of the specimens depart considerably from planar sections and also that the apparent angles are not equal since the weight on the upper sections is much greater than that on the lower ones. Hence the average angle obtained from the length of the zigzag specimen was not reliable. He therefore abandoned these methods and used the flexometer which was developed by Schiefer at the National Bureau of Standards over 15 years ago [4, 5]. He measured fabrics of different weaves, weights, fibers, and mixtures of fibers and suggested limits for classifying fabrics with respect to crease-resistance [6]. Because the number of fabrics tested was believed to be insufficient, the suggested limits may have to be changed as more data become available and are compared with the results of performance tests.

Frenzel reviewed the work of A. ten Bruggencate [6] and of W. Fischer [3] and alluded very superficially to some of the research work published in the United States. He and R. Reiman of the machine shop of the Textile Engineering School constructed a new instrument and applied for a German patent [7]. This instrument is illustrated schematically in Figure 62. The specimen S is mounted across LL'. A force F is applied and the specimen is folded between the two plates LM and $L'M'$, which rotate integrally with the two sectors Q and Q' about the center O. The force is indicated on the calibrated scale T by the deflection of a pendulum N. In the design of this instrument, Frenzel made provisions for adjusting the plates LM and $L'M'$ to allow

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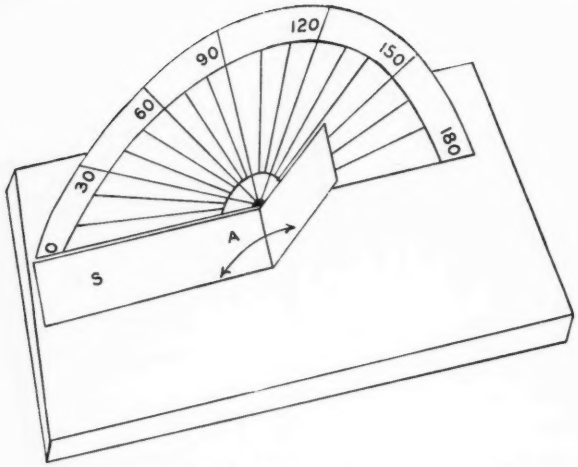

FIG. 60. *Schematic drawing for measuring creasing angle.*

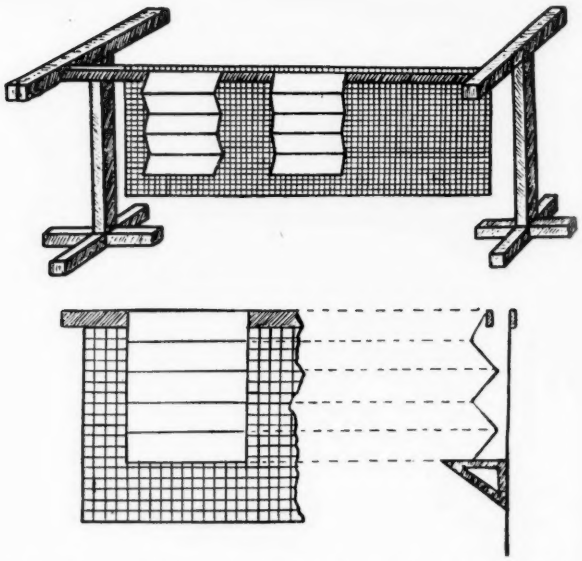

FIG. 61. *Schematic drawing for measuring multiple creasing angles.*

for the difference in the thickness of the specimens. This adjustment is accomplished by adjusting P and P', thereby rotating the plates LM and $L'M'$ about L and L' such amounts that when the sectors Q and and Q' are rotated until LM is parallel to $L'M'$ the distance between these two plates is twice the thickness of the specimen. Since this provision was considered to be a novel feature by Frenzel in his instrument, a feature also provided for in the flexometer but never found necessary in use, it is apparent that he was not thoroughly acquainted with the constructional details of the flexometer and the mathematical treatment. The quantities measured by Frenzel are the same as those used by Schiefer and A. ten Bruggencate—namely, the work required to fold a specimen through a given angle and the work recovered when the applied force is removed. The former was taken as a measure of stiffness. The ratio of the work recovered to the work expended in folding expressed as a percentage was taken as a measure of flexural elasticity or resilience. The difference between these two quantities of work, which is the work dissipated in creasing the specimen, also expressed as a percentage of the work expended in folding, was taken as a measure of the tendency of the fabric to crease or wrinkle.

2. Flexural Endurance

(a) Fibers

The flexural endurance of single fibers was measured with an instrument shown schematically in Figure 63. Two rotating clamps are positioned at

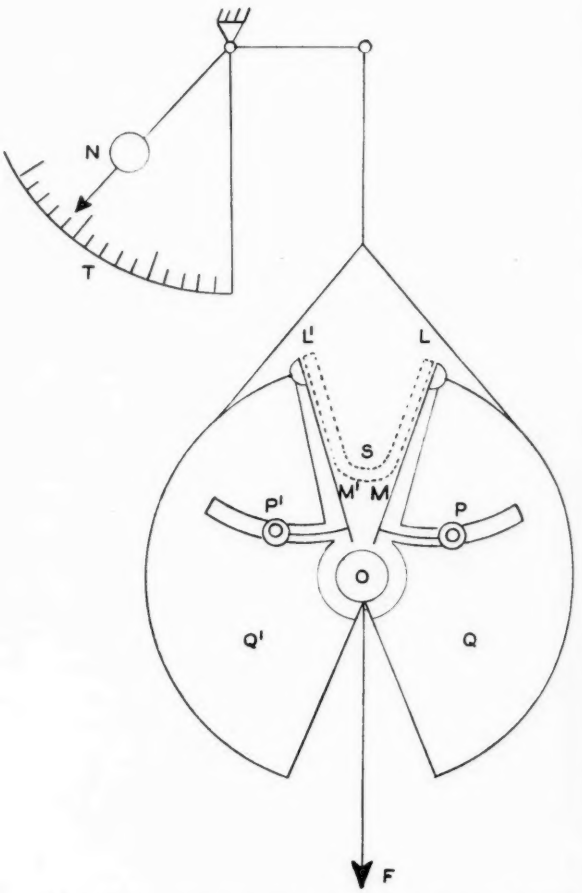

FIG. 62. *Schematic drawing of proposed modification of flexometer.*

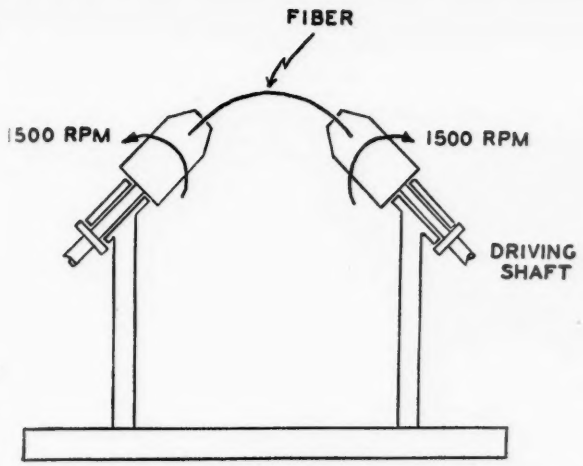

FIG. 63. *Schematic drawing of fiber flexing tester.*

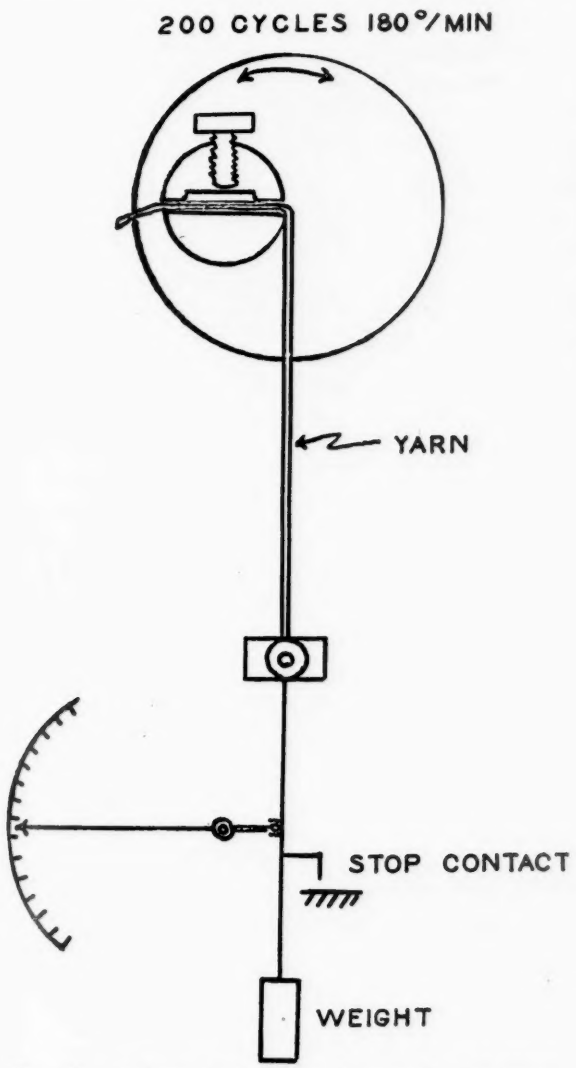

FIG. 65. *Schematic drawing of yarn flexing tester.*

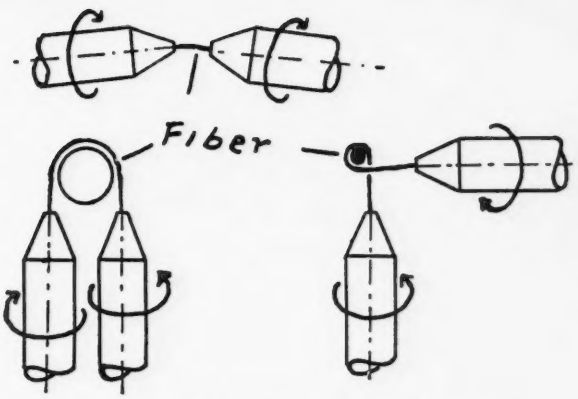

FIG. 64. *Schematic representation of fiber flexing tests.*

right angles to each other and their axes lie in a vertical plane. The fiber is inserted in the two clamps so that it assumes the shape of a quarter-circle in the axial plane of the clamps. The fiber is tangential to the axis of a clamp at the point of contact. The two clamps are synchronized to rotate at a speed of 1,500 r.p.m. In each rotation an element of the fiber of the central portion goes through a cycle of tension and compression resulting from flexural deformation. The number of rotations required to cause failure is recorded. The results were too variable to be included in the computation of a fiber wear index in the research conducted by Oestermann at Schachenmayr, Man & Cie, at Salach. In addition to the method of mounting the fiber as shown in Figure 63, tests have been suggested by Ecker [16] in which the fiber is mounted as shown by the three illustrations in Figure 64.

(*b*) *Yarns*

The flexural endurance of yarns was measured with an instrument shown schematically in Figure 65. One end of the yarn is mounted in a clamp which oscillates through 180 degrees two hundred times per minute. From the lower end of the yarn a weight is suspended to which is attached a pointer which indicates the extension during a test on a fixed scale. The number of oscillations required to produce rupture of the yarn and the extension are recorded.

(*c*) *Woven Fabrics*

The flexural endurance of woven fabrics was measured with several instruments. The Schopper

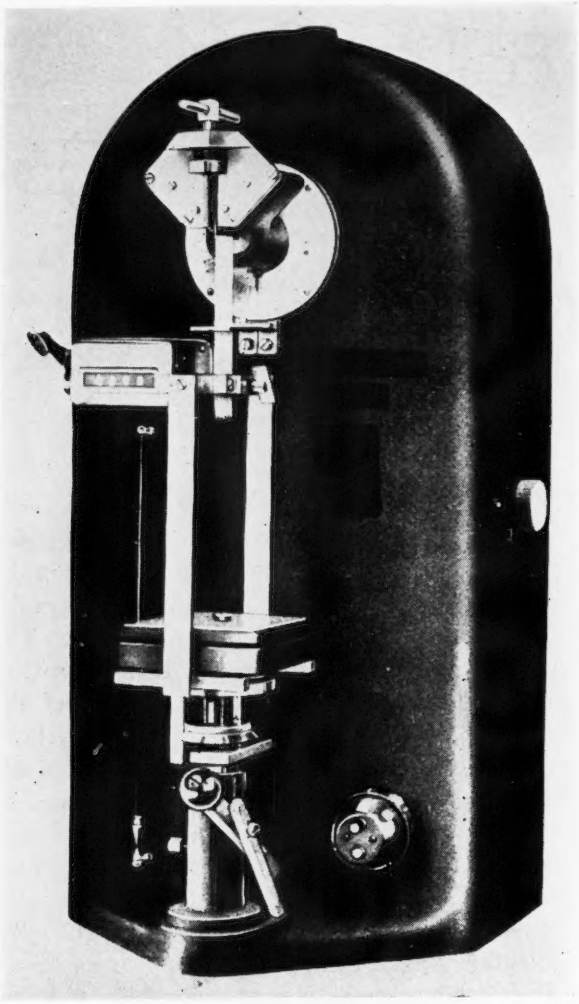

FIG. 66. *Schopper fabric flexing tester.*

folding endurance tester, shown in Figure 66, was used most generally. One end of a specimen 3 cm. wide and 20 cm. long is fastened in a clamp which oscillates through an angle of 180 degrees about two hundred times per minute. A weight equal to 10 percent of the breaking strength is usually suspended from the other end. Extreme care must be exercised in aligning and fastening the specimen in the oscillating clamp. The number of oscillations required to rupture the specimen is recorded. In some experiments the decrease in breaking strength after a given number of oscillations is determined.

Another device for measuring the flexural endurance is shown schematically in Figure 67. Eight specimen strips S are fastened to the base plate P and to the weight W_1, and eight specimens are similarly mounted to the weight W_2. The weights W_1 and W_2 are alternately raised and lowered by a reciprocating arm, A. The decrease in breaking strength after a given number of flexings is determined. Risch found that the linen yarns of cotton-linen mattress fabrics decreased an average of 6 and 18 percent after 20,000 and 100,000 flexings, respectively, whereas the average decrease for cotton was only ½ percent after 100,000 flexings [9].

Still another flexing device for fabrics is shown schematically in Figure 68. One end of the fabric strip is fastened to a fixed clamp and the other end is fastened in a clamp which reciprocates horizontally a total distance of about 4 inches. The fixed clamp can be adjusted vertically to make the distance between the two clamps sufficient so that the fold in the fabric strip is not restricted—that is, it is not compressed by the application of pressure. In a test the fabric strip is folded back on itself, first with one side on the inside of the fold and then with the other side on the inside. It is claimed that this test evaluates the tendency of one kind of fiber to work out of fabrics which are made from yarns containing a blend of several kinds of fibers. A modification of this type of machine has been described by R. Stoll [10] and is shown schematically in Figure 69. In this modified machine the fabric is placed under a known amount of pressure, the same side is always on the inside of the fold—that is, the fabric fold is not reversed—and an abrasion of the fabric against itself is produced in addition to the flexing. The change in breaking strength is determined as a function of the number of oscillations.

(*d*) *Knitted Fabrics* (*Hosiery*)

The flexural endurance of women's hosiery was measured by using the so-called Frazier hosiery test-

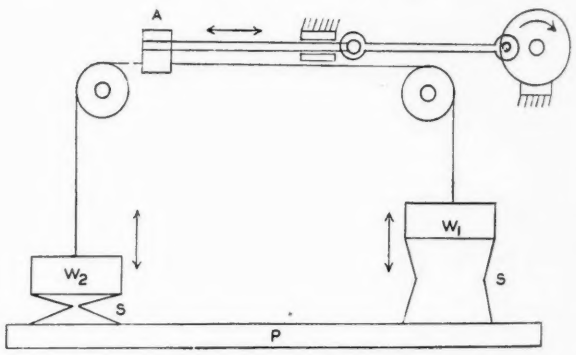

FIG. 67. *Schematic drawing of fabric flexing.*

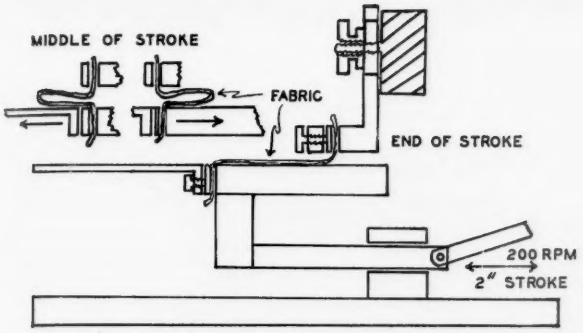

FIG. 68. *Schematic drawing of double fabric flexing tester.*

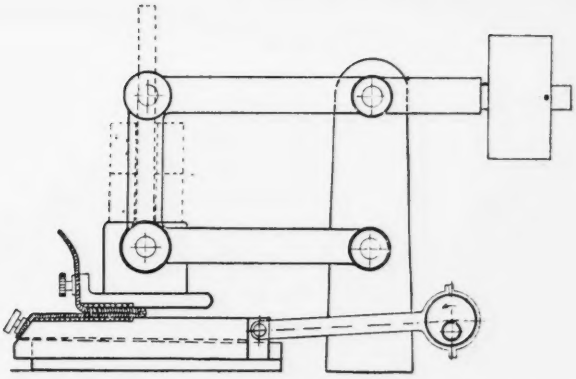

FIG. 69. *Schematic drawing of Stoll fabric tester.*

ing machine which was developed by Schiefer [11] at the National Bureau of Standards. Kors [12] reported on the results of extensive tests on silk hosiery showing the effect of dyeing, different finishes, different pH of dye bath (pH 4.2 to 9.8), different twists in the yarn, different times of dyeing without a protective colloid in the dye bath, different times of dyeing with a protective colloid in the dye bath, and different protective colloids in the dye bath. The tests on cuprammonium and viscose hosiery are as extensive and include effects of laundering. Kors concludes that with this machine it is not only possible to determine quantitatively the effect of finishing agents but also to control quality in manufacturing, dyeing, and finishing.

3. Thickness, Compressibility, and Compressional Elasticity

The thickness of textiles is usually measured at two pressures using dead weights. The functional relationship between thickness and pressure is assumed to be hyperbolic and the two points, plotted on logarithmic paper, are connected by a straight line. The value at a pressure of 50 g/cm² is usually taken as the thickness of a fabric. For compressible textiles various pressures are used but 5 g/cm² and 10 g/cm² are the most common. The difference in thickness at pressures of 10 and 100 g/cm², which is the slope of the line plotted on logarithmic paper, is taken as a measure of compressibility. The specific compressibility is this value divided by the thickness at 10 g/cm².

The method for measuring bulk elasticity, which is generally evaluated for staple rayon, is not standardized and each laboratory uses a slightly different procedure and equipment. The general tendency is to place 10 grams of loose fibers in a beaker of about 11-cm. inside diameter. The fibers are then compressed by a load of 50 grams for 1 minute, after which the load is removed and the height of the upper surface is noted on three scales placed on the beaker 1 minute after removal of the load. This value is designated by *a*. The fibers are then compressed by a load of 1 kg. for 1 minute, the load is removed, and the height *b* is read after 1 minute. Finally, a load of 50 grams is again placed on the fiber for 1 minute, the weight is removed, and the height *c* is read after 1 minute. The value of *c* expressed as a percentage of *a* is taken as a measure of the compressional elasticity.

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ing 10 and 20 times at pH of 7 and 10 are shown for viscose, acetate, and cuprammonium rayons.

3. Die Knitterfestigkeit und ihre zahlenmässige Feststellung (Eine neue Methode zur Bestimmung der Biegeelastizität). (Crease-resistance properties and their numerical evaluation (a new method for determining flexural elasticity).) W. Fischer. *Melliand Textilber.* **22**, 217–18 (1941).

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The effects of testing conditions on the results obtained with the Schopper bending tester are shown. Results are presented for fabrics made from different fibers, yarn and fabric construction, and finishing treatment.

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A new instrument is described which employs a special pendulum for applying the load to compress fibers in a vessel.

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16. Ein Beitrag zum Problem der mechanischen Stoffabnutzung. (A contribution to the problem of mechanical wear of textile materials.) J. Ecker. *Melliand Textilber.* **22**, 318 (1941).

Part IV. Miscellaneous

1. Spinning Tests

With the intense interest in Germany in the development of new fibers, mostly variations on viscose rayon, there was a need for small-scale testing of spinning characteristics. This was met by a device, about the size of a small desk, called the "Spinntaxer," made by Rudolph Knote in Leipzig, as shown in Figure 70. The device has two parts, a small card, requiring only 45 g. (0.1 lb.) of staple, and a single-ring spinning spindle. In use [1] the staple is given a preliminary carding and removed as fleece, and a second carding, from which it is removed as top. This is then drafted and spun into a yarn in the range from 6 to 10 English number (cotton count). The breaking strength of the yarn so produced is compared with the breaking strength of similar yarn produced from comparison materials. The "Spinntaxer" can be used to study the effect of twist, or of lubricants applied to staple. The yarns produced were somewhat lower in utilization of the inherent strength of the individual fibers than those produced by standard large-scale spinning, since standard production usually gives from 50 to 55 percent of the fiber strength, but the "Spinntaxer" gives only about 45 percent. Nevertheless, the value of such a device for development and testing work is obvious.

2. Measurements on Staple

A constant care in each of the rayon plants was the maintenance of uniformity of staple. A large proportion of the personnel and the space of the rayon laboratories was taken up with this control work. As nearly as could be observed, however, the interpretation of production control appeared to be intuitive rather than systematized by the control-chart methods which the American Society for Testing Materials has helped to introduce in this country.

Every rayon laboratory was equipped with knives and torsion balances for determination of denier. The staple was combed and stretched across a steel anvil, about 2 cm. wide. Two knives operated by a lever cut out the staple at the two sides of the block. The operator would then count out bundles of 50 fibers for weighing to determine the denier. The same method was often applied to continuous filament.

One of the few electronic instruments seen in German textile laboratories was an importation from Holland—namely, Gonsalves' [2] device for determination of denier on an individual filament. This operated on the basic law of the violin string—that the frequency (pitch) is dependent on the length, the mass of the fiber, and the tension on it. Single fibers were attached to the element of the loudspeaker unit, which could be tuned until resonance was seen in the fiber. The tuning control was calibrated to read the frequency. From this the weight per unit length—that is, the denier—could be found. The device was calibrated by cutting segments from continuous-filament rayon, and an accuracy of 3 to 4 percent was claimed.

Alternatively, the methods developed for wool could be used. These were two: one was the projection of a large number of cross sections on the screen (the standard section cutter appears to be identical with that of Hardy of the U. S. Department of Agriculture); the other method, the "Rapid-Lanometer," measures the area of a bundle of fibers in

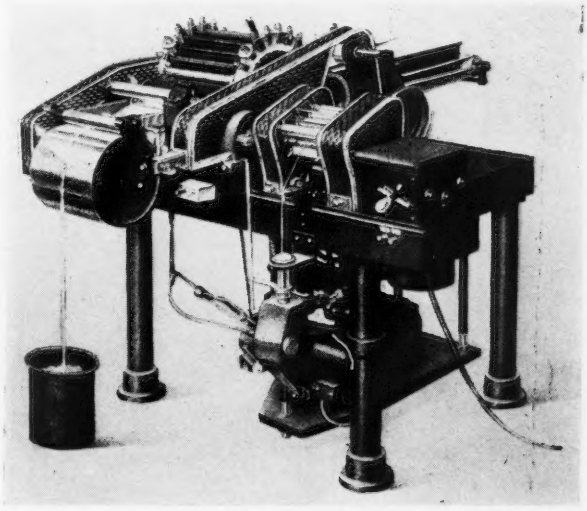

FIG. 70. *Spinntaxer.*

a square wedge, under a standard pressure, as shown in Figure 71.

Staple length was usually determined in the combing device shown in Figure 72, which was developed by Johannsen and made by Zweigle. The chief difference between this and the Suter-Webb Duplex Sorter used for cotton, or the Suter Wool Sorter, is in the hingeing of the two banks of combs so that the upper bank can be pressed down into the lower, thus reducing the sorting interval to one-half.

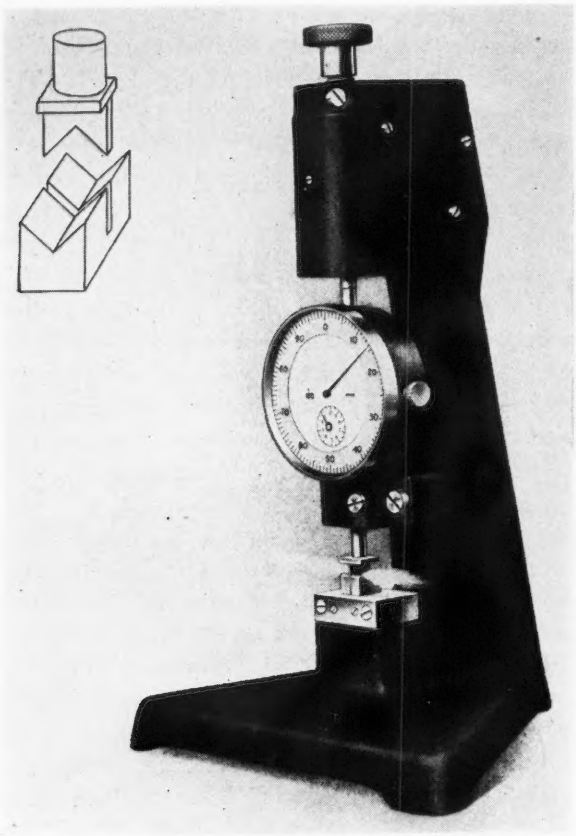

FIG. 71. *Rapid-Lanometer.*

3. Shrinking and Creping Measurements

In Germany there appeared to be emphasis on shrinkage measurements at the yarn stage, as well as on the fabric, which is currently an important question in this country. A convenient device for multiple observation of yarn shrinkage was seen in several laboratories. This consisted of a rack from which ten yarns could be hung, in front of a sheet of cross-section paper. Such a rack would be about 2 meters high, with the yarns hung dry in the upper half for initial observation. The lower half was filled by a frame carrying a corresponding number of glass tubes which could be raised to immerse the respective yarns. After a suitable period, the glass tubes could be racked down again and the yarn length observed after drying.

Another device was well adapted to observation of creping tendency by determination of the force of contraction. In this, a battery of levers and indicating pointers is arranged to load yarns with a series of weights, increasing from one lever to the next. The creping bath is then raised to immerse the yarns. Some of the weights stretch the yarn; some produce less than the creping tension, and on the plot of change of length against load the point at which there is no change of length indicates the creping tension.

A third device used to study shrinkage from the point of view of yarn uniformity was seen in Weltzien's laboratory at Krefeld. A similar device was recently described by Eyre [3] in England. The yarn is wound

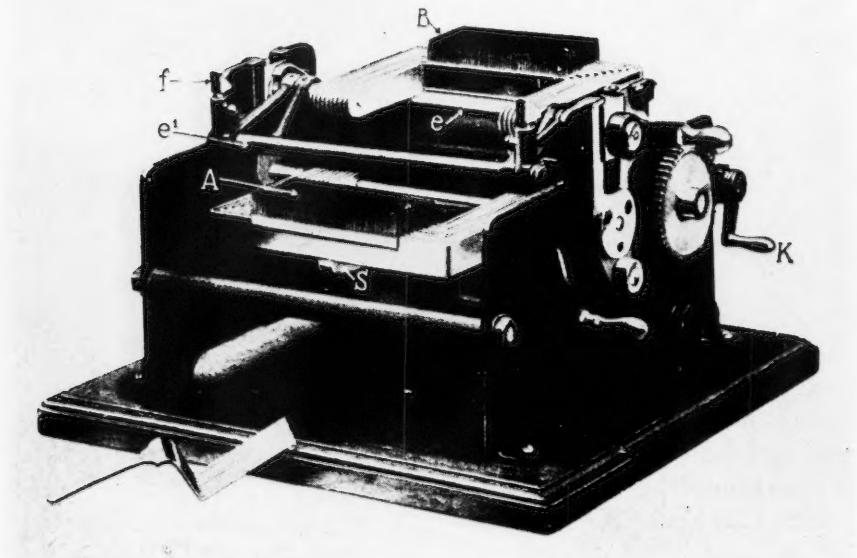

FIG. 72. *Johannsen-Zweigle staple-length tester.*

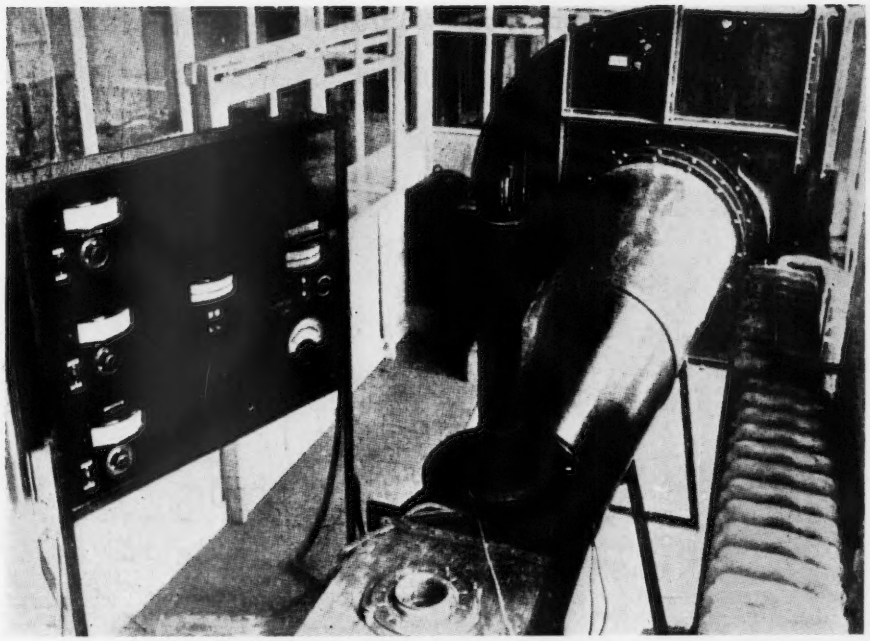

FIG. 73. *Mecheels Wind Tunnel Thermal Insulation Tester.*

under constant tension onto a cylinder, where it is marked by an indelible ink in a straight line drawn the length of the cylinder. The yarn is then wound off in a skein, treated with water, alkali, or otherwise, dried, and wound onto the cylinder again. The markings now produce a spiral, because of shrinkage, and variability along the yarn is revealed in the pitch of the spiral.

4. Swelling

In the rayon-dominated textile picture in Germany, methods to improve the strength and durability of rayon occupied a position second only to methods of production. The leading idea was that if the swelling of rayon in the wet state could be prevented or diminished, the damage in washing and abrasion under moist conditions would be reduced and its period of usefulness extended. A standard method of measuring swelling was in terms of water retained after centrifuging. The essential points of this method were: wetting-out for 30 minutes in distilled water plus wetting agent at 20°C; centrifuging in a basket centrifuge at a specified centrifugal acceleration (600,000 to 800,000 cm. per second per second) for 2 minutes. The decrease in swelling was calculated as the difference in retention between untreated and treated material, divided by the water uptake of untreated material. Typical values resulting from such measurements are the following, taken from a study by Wagner [4]:

Finish	Water uptake		Swelling decrease	
	After 1 wash (%)	After 50 washes (%)	After 1 wash (%)	After 50 washes (%)
Regular	86	91	—	—
Formaldehyde	60	64	33	28
Resin	61	78	32	12

A technique of estimation of swelling by dyeing was also used which was carried out as follows:

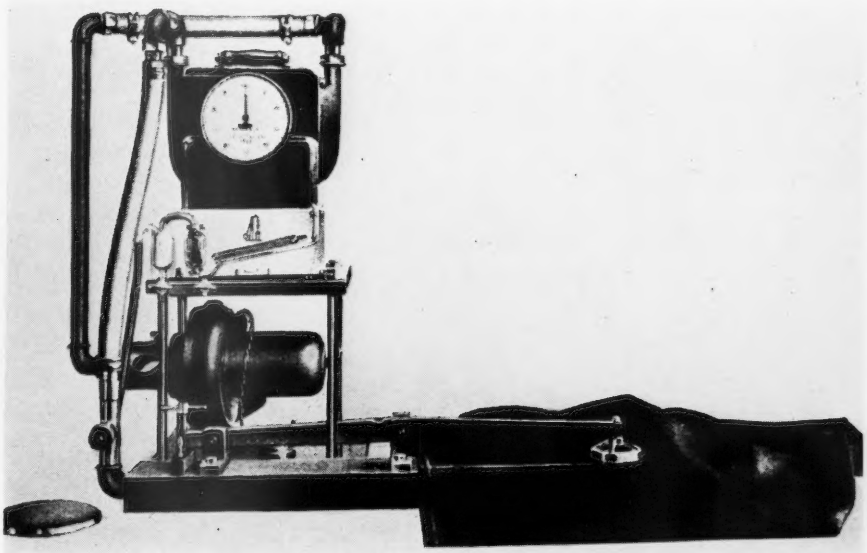

FIG. 74. *Air-permeability tester.*

Sizing or soluble material is removed from fabric by appropriate purification. The fabric is then soaked in sodium hydroxide solution of 12° Baumé, 8- to 9-percent NaOH, cold. The uniform wetting of the piece with alkali, which is very important, can be improved by addition of a wetting agent. The fabric is rinsed in warm and cold water, acidified in dilute formic acid, rinsed, and dried. It is dyed with 0.2- to 0.5-percent Sirius light blue B, in a ratio of goods to solution of 1 : 20 to 1 : 30, with 0.5 g. Igepon per liter and 5 to 15 percent salt. Starting at a temperature of 40°C, the dye bath is heated to boiling. The time of dyeing varies, with the size of the piece, from 30 to 60 minutes. After the dyeing, the fabric is rinsed and dried.

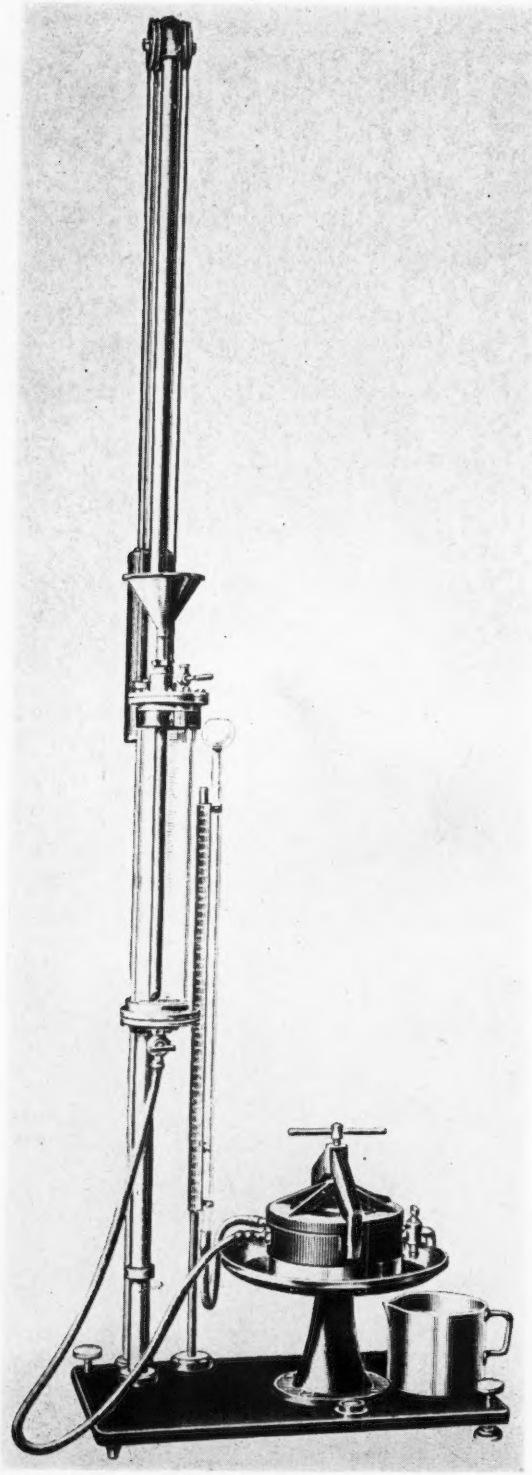

FIG. 75. *Hydrostatic-resistance and flow tester.*

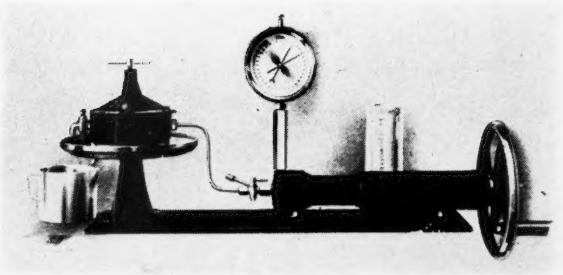

FIG. 76. *Hydrostatic tester for higher pressures.*

The dyed piece is compared with standards, dyed by the same procedure, which have had their degree of swelling determined by the other method. An eight-step scale from no-swelling-resistance to good-swelling-resistance is used.

5. Testing the Warmth of Fabrics

German workers had a natural interest in the warmth of clothing, but the judgment of Herr Sommer, head of the textile division of the Materialprüfungsamt in Berlin, that the measurements made did not represent a definite physical quantity, is certainly justified. However, the German activity in this field has several points of interest to American workers. One is the use of wind tunnels to introduce the effect of moving air. Probably the most elaborate of these tunnels was that of Mecheels at München-Gladbach, shown in Figure 73. The illustration shows the test cylinder, wrapped in cloth, standing on top of the tunnel. The test area is 1 square meter. Although higher wind velocities could be obtained, the usual working speeds were 5, 10, and 20 m. per second, or from 11 to 45 m.p.h. Other workers used lower velocities or attempted to

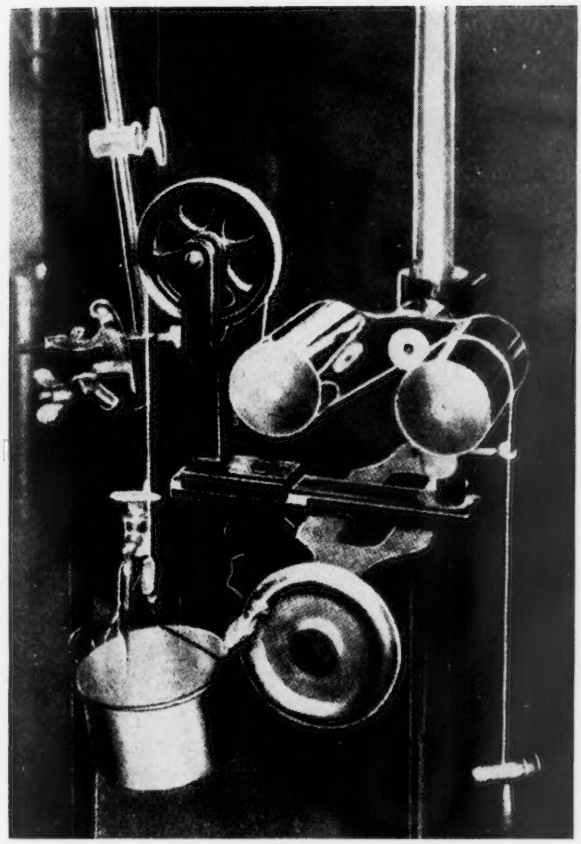

FIG. 77. *Yarn friction test.*

reduce turbulence around the test cylinder by streamlining it.

In general, the cooling curve was used as the basis for comparison. Sommer proposed that the factors of thickness and porosity should be considered by comparing fabrics in terms of the equivalent air layer, which he defined as the product of thickness times the fraction of the volume of the fabric which is occupied by air.

6. Testing the Effect of Cloth Surface on the Sensation of Warmth

A device for comparing the effect of different surface characteristics on the sensation of warmth was seen at the textile laboratory of Vereinigte Glanzstoff, Obernberg. This device had been developed by the filament rayon department, in connection with abraded yarns, in the attempt to make filament rayon take on more of the character of spun staple. It consisted of a grid of wires which were simultaneously the source of heat and the means of measuring it as a resistance thermometer. Current sufficient to keep it at body temperature was let pass through the grid while it was exposed to air. When a piece of fabric was laid on it, the grid was cooled, and the more it was cooled the smoother the surface of the fabric and the better the thermal contact. This cooling changed the resistance, and the effect on the current was followed on a recording ammeter. The largest changes of temperature were observed with filament rayon, and the smaller the changes the more hairy the surface.

7. Air Permeability

The factor of air permeability or resistance to wind penetration enters into the testing of clothing in the wind tunnel, or to the protection afforded the wearer. It also is a convenient measure of the porosity of fabrics, and is related to the effect of water-repellent treatments on fabrics. The usual device for measuring this characteristic was that made by Schopper (Figure 74), in which air is drawn through the fabric and through a gas meter. The pressure across the fabric is indicated by a manometer, and is standardized at 20-mm. water pressure. The results are expressed as liters flow per minute per 100 sq. cm. of fabric at this pressure.

8. Hydrostatic Resistance

The resistance of water-repellent or waterproofed fabrics to hydrostatic pressure was regarded as a valuable test, as it is in this country. Figure 75 shows a device for measuring hydrostatic resistance,

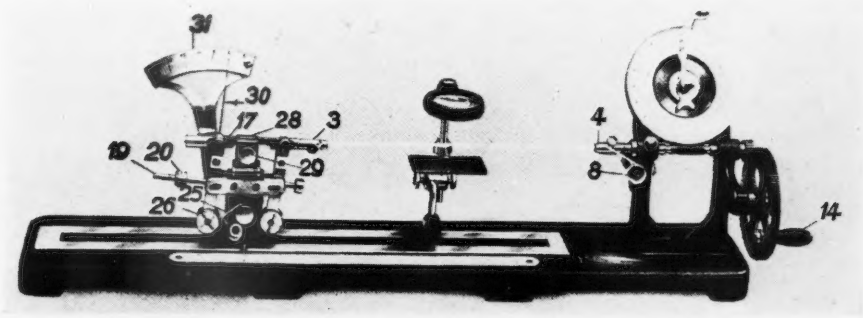

FIG. 78. *Twist tester.*

using the appearance of the first few drops on the surface of the fabric as an end point, as in the test of the American Association of Textile Chemists and Colorists. In addition, the reservoir is calibrated to permit measurement of the amount of water flowing through the fabric, as an alternative test.

For fabrics intended to be waterproof—that is, which have a continuous film sealing the pores—larger hydrostatic pressures are needed than for water-repellent fabrics in which the pores are not sealed. Figure 76 shows a compact tester for higher hydrostatic pressures.

9. Shower Testing

Two general types of shower or artificial rain tests were in use. One, proposed as "Norm" (DIN 61700), resembles somewhat the A.A.T.C.C. impact test, but is more severe in that it calls for greater distance of fall (2 meters), longer exposure (successive periods of 5, 10, and 15 minutes on the same sample), and a larger area involved in the test (28 $\times$ 38 cm. with the longer edge at 45° to the vertical). The fabric is suspended across an opening without backing. The spray head consists of 361 capillary tubes in an area 30 $\times$ 30 cm., each releasing one drop per second, totaling 1.5 liters per minute. Evaluation is by weighing the specimen to measure the amount of water absorbed.

In the other general type, of which the Bundesman tester is the most usual representative, the impact effect of the falling drops is supplemented by a wiping action on the undersurface of the fabric.

10. Yarn Friction

One method of measuring the friction of yarns is shown in Figure 77. The yarn passes over two nonmoving polished steel cylinders. One end carries a container, into which water is allowed to flow at constant rate, and the other end carries a counterweight. Friction is measured by the time interval until the strand slips. Mecheels has proposed that the quality of softness can be measured in a composite way, as directly proportional to compressibility and inversely proportional to roughness.

Another device for testing friction on running yarn consisted of a winder which draws the yarn through a friction disc, and a tension indicator.

11. Twist

Devices for measuring twist were usually equipped with tension indicating systems, so that twist could be determined by untwisting and twisting in the opposite direction to equal tension. The original twist is then half the number of turns required to do this. Figure 78 shows such a device, equipped with a magnifier for visual observation.

12. German Standards Organization

Typical of the situation in other countries, many independent standardizing agencies had sprung up during the course of the years in Germany, and although they were all seriously endeavoring to contribute to the cause of standardization, the situation was quite chaotic.

In 1917 the first attempt to unify all of the agencies began, and finally in November, 1926, the resulting Deutscher Normenausschuss e. V. took form. This organization, identified as DNA, consisting of a joint committee composed of representatives from the government, from the manufacturers, and from the consumers of manufactured products, was the final authority on all German standards.

Associated with DNA were many suborganizations which concerned themselves with specific industries and fields. These subgroups represent very broad interests, including even the Army, Navy, and Air Corps.

The functions of DNA may be classified in five primary categories:

1. Definitions—Official approval and definition of technical concepts, terms, abbreviations, and symbols.
2. Dimensions and Tolerances—Dimensional standards and tolerances of commercial products.
3. Performance Standards—Quality performance standards for products and machines, and for packing and delivery of goods.
4. Testing Standards—Standard test methods.
5. Safe-Practice Standards—Machine and equipment operating and maintenance codes.

The evolution of a standard follows the approximate course (oversimplified for the sake of illustration) described below.

Any person or organization may propose or request a standard. This proposal or request will be referred to one of the specific technical subcommittees of DNA. If there is no subcommittee in the field in question, it will be referred to the subcommittee in a related field or a new specific subcommittee will be formed. After the subcommittee has prepared a tentative standard, it is published in various trade and scientific publications (the *Melliand Textil-*

berichte being one of those used in textiles), inviting discussion. After these discussions result in agreement, the final draft is submitted to DNA for approval. When approved by DNA, the standard is assigned a number and issued as a Deutsches Industrienorm, or DIN. In the attempt to popularize the use of DIN, the actual significance of the abbreviation (for "Deutsches Industrienorm") was played down and it was popularly used to mean *"Das ist Norm."*

The German Textile Standards in their final form, although earlier releases followed a somewhat different pattern, were prefixed with the letters "DIN" and followed by the standard number. DNA had reserved DIN numbers from 60,000 to 64,999 for textiles.

Prior to the war, the DNA was cooperating with the standards organizations of 26 foreign nations. Some of the DIN's have been available in the United States for various industries. Those covering textile testing representing the most recent issues have been collected since the war and have been deposited in the Library of the National Bureau of Standards.

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The assistance of Miss Josephine Blandford in preparing many of the illustrations is gratefully acknowledged. The authors also wish to take this opportunity to express their appreciation for the major contribution made to this work by their teammates and their associates in the Armed Forces, without which it could not have been done. Finally, the untiring efforts of Sergeant Al. Hearn, his skillful operation of the vehicle and safe driving for the many thousands of miles in Germany, his friendly disposition, and willingness to assist in many ways, all contributed immeasurably to the success of the investigations and are deeply appreciated and gratefully acknowledged by Schiefer and Kropf.

Mechanics of Elastic Performance of Textile Materials*

I. Development of an Elastic Performance Coefficient in Tension

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This is the first of a series of papers dealing with the mechanics of elastic performance of textile materials.

Abstract

The factors which affect the textile quality usually known as *resilience* are discussed, and a normalized coefficient is derived which quantitatively expresses the degree of resilience of textile fibers. Use of the term "elastic performance," rather than "resilience," is suggested. The dependence of elastic performance upon the fundamental load-deformation properties of textile materials is considered and it is demonstrated that the elastic performance coefficient reflects the effect of immediate-elastic, primary-creep, and secondary-creep deflections.

The coefficient is indicated to be applicable to all types of loading: tension, compression, bending, torsion, etc. All that is required for its calculation is a load-deformation diagram under uniform, controlled cyclical loading and unloading.

Data are presented upon the *tensional* elastic performance of two different materials—continuous filament acetate rayon and fully drawn nylon—under various magnitudes of tension loading. Variations in elastic performance with yarn geometry—that is, twist—are given for the acetate rayon yarn.

The evaluation of elastic performance under compression and other types of loading will be presented in a future paper.

ELASTICITY and RESILIENCE have been frequently referred to as "obscure textile properties" and have been defined and evaluated in many ways in the textile literature. In these definitions and evaluations an attempt has been made to express tactile or visual impressions in concise terms either verbally or by numerical indices.

Actually these so-called "obscure properties" are not properties per se, but are, rather, complex interactions of many factors, both inherent in the fiber and resulting from the geometry of the yarn or fabric structures, and hence require careful analysis based upon the physical properties of the materials and the stress distributions within the yarn or fabric structures.

Both elasticity and resilience may exist in the classical sense without reference to the extensibility or softness [8] of the structure, yet many investigators [1, 14] have attempted to include such properties either in their definitions or in their numerical indices. Furthermore, time effects have either been ignored or inadequately accounted for [7, 10, 11] in the attempt to correlate tactile or visual impressions with quantitative evaluations.

Areas of load-deflection (hysteresis) loops have also been suggested as a criterion of resilience [3, 12, 14] as have relationships of areas under the loading and recovery curves. It should be immediately evident that two entirely different materials could exhibit identical area relationships and that the converse situation could also exist.

Scientifically, the term "elasticity" has been used to refer to the ability of a material to return spontaneously to its former size, shape, or attitude after being strained, whereas "resilience" connotes the amount of strain energy present in a stressed system. Textilewise, the term "elasticity" is used most frequently probably to mean the "stretchiness" of the ma-

* Presented in part at the February, 1946, meeting of The Fiber Society at Philadelphia, and also at the Textile Conference, American Association for the Advancement of Science, July, 1946, at Gibson Island, Maryland.

terial, which includes the concept of extensibility as well as ability to recover, whereas the term "resilience" ordinarily connotes the quality of softness and at the same time the ability to recover from large deflections. In both cases the extensibility or softness are included but the all-important time factor is not.

In order to avoid this confusion of interpretation and definition, the term "elastic performance" is suggested as being more expressive of the factors involved when materials are said to manifest elasticity or resilience textilewise. The extensibility and softness properties are not prerequisite to elastic performance and hence should be treated and evaluated as separate criteria of performance.

It is generally agreed that research aimed toward scientifically evaluating material properties quantitatively for certain specific end uses is of major importance. The broad end-use requirement of textiles is durability. This property refers generally to the ability of a material to exhibit its original properties after repeated use; hence the reproducibility of stress-strain properties exhibited by a material following cyclical loading and unloading is of paramount importance [4] and may be defined as its elastic performance.

During recent years a new and dynamic attack has been made on the age-old problem of defining, in quantitative terms, the performance characteristics of textile materials and structures. The work of Peirce and coworkers [9], Leaderman [6], Eyring and coworkers [2], Smith [13], and others has focused attention on the fact that textile performance is governed by the same physical and engineering concepts used so successfully in the evaluation of the more classical structural materials—that is, wood, steel, concrete, etc.—and that the basic difficulty in applying these concepts to textiles lies in the fact that textile materials deviate in their elastic performance from such materials as a result of the manifestation of delayed elastic and plastic after-effects [6].

It has become necessary, therefore, to introduce many rather complex concepts in an effort to interpret the behavior of textile materials. Inevitably, considerable confusion has resulted among textile technologists in attempting to evaluate these new considerations.

For this reason it has been deemed advisable, in introducing this new series of papers on elastic performance, to review first these concepts as they relate specifically to an understanding of the elastic-performance coefficient and its application.

When load is impressed upon a material it suffers deformation which may be divided into two major components, one taking place immediately, the other over a period of time. These components may be defined as (1) immediate elastic deflection and (2) delayed deflection. Delayed deflection may be further subdivided into recoverable and nonrecoverable deformations thus: (1) primary creep (delayed elastic, recoverable); and (2) secondary creep (permanent set or plastic flow, nonrecoverable).

Elasticity or resilience may be generally defined as the ability of a material to return to its original form or shape upon the removal of a previously applied load.

In order for a material to be perfectly elastic it must manifest no delayed deflections—that is, it must exhibit only immediate elastic deflection permitting it to recover immediately and completely upon load removal. Such perfectly elastic materials are represented by engineering materials at room temperature for loads below the elastic limit.

Textile materials exhibit both primary and secondary creep deflections. When secondary creep is removed a material exhibiting immediate elastic deflection and primary creep may recover completely in time, depending upon many factors affecting creep recovery. When a material recovers completely, although the recovery is delayed, it may be classed as a completely elastic material in contrast with perfectly elastic which connotes immediate and complete recovery.

If the delayed deflections were not present in textile materials their action under load might be determined by some such technique as an instantaneous dead loading procedure since time would not be a dominant factor in evaluating performance from an elastic standpoint. The manifestation of primary and secondary creep, however, makes a consideration of the time effects of paramount importance. The magnitude and the rate of primary creep, and the magnitude of secondary creep must be accounted for.

Steel at room temperature for loads below the elastic limit is an example of a perfectly elastic material. If load is applied at zero time and allowed to act for time t, and then removed, the load-time relationship is that illustrated in Figure 1.

The deflection-time relationship for such a material will be that shown in Figure 2.

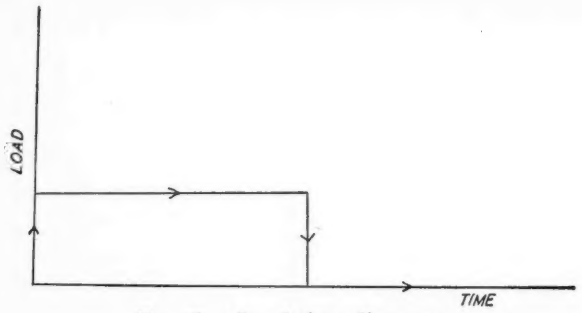

FIG. 1. *Load-time diagram.*

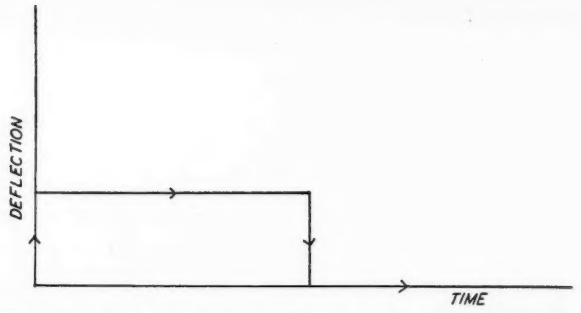

FIG. 2. *Deflection-time diagram (perfect elasticity).*

Thus, the deflection is constant with time and the specimen returns immediately and completely to its original form upon load removal, the magnitude of the deflection being proportional to the load. For these conditions the load-deflection diagram is that of Figure 3.

For perfectly elastic materials, then, it will be seen that the load-deflection relationship is linear and materials manifesting perfect elasticity vary from one another elasticwise only as their stiffness or softness —that is, their modulus of elasticity, which is represented by tan θ, in the diagram.* The shape of the load-deflection diagram is unchanged, remaining always a straight line inclined at some angle to the axes up to the elastic limit.

Consider now a material which is imperfectly elastic. In this case there are three components of deflection which interact: the immediate elastic deflection, primary creep, and secondary creep. The shape of the load-deflection diagram is the result of the interaction of these three components.

If a load is applied to such a material at zero time and allowed to act for time, t, and is then removed, the load-time relationship is the same as that shown in Figure 1.

However, in contrast to the similarity of load-time relationships between perfectly and imperfectly elastic materials, the deflection-time relationship differs because of the presence of the delayed components. This difference is shown in Figure 4 (compare with Figure 2).

The deflection is not constant with time. In this case, there exists an immediate elastic deflection proportional to the load and a delayed deflection which increases at a decreasing rate with time. Upon load removal there is an immediate elastic contraction equal to and opposite to the immediate elastic deflection and a delayed contraction which increases at a decreasing rate with time. The recovery is not complete, however, and the material does not return to its original unloaded condition. This failure to return is a function of the magnitude of secondary creep manifested by the material.

A typical load-deflection diagram of such material is that of acetate rayon (Figure 5).

The load-deflection diagram is not linear since the delayed components affect its shape; hence it is important to consider the shape of the diagram in determining any index of elastic performance of nonlinear materials such as textile fibers and other textile structures.

In the example just cited the specimen does not return to its original condition because of the presence of secondary creep. This component may be removed by repeated load application and removal, leaving only the immediate elastic deflection and the primary creep deflection. The process is known as mechanical conditioning, and for all practical purposes it may be completed in a relatively few repeated loading and unloading cycles.

Consider the load-time relationship for such a mechanically conditioned (secondary creep absent) material (Figure 1).

The deflection-time relationship is indicated in

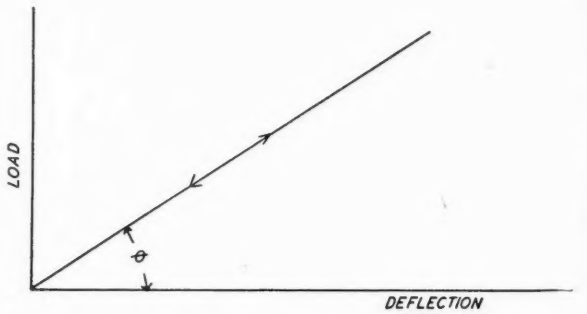

FIG. 3. *Load-deflection diagram (perfect elasticity).*

* Length and cross-sectional area must be known in order to derive a true modulus.

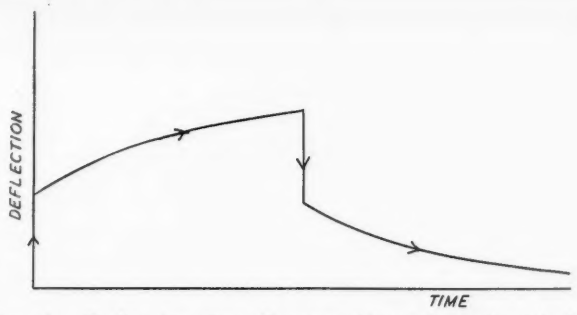

FIG. 4. *Deflection-time diagram (imperfect elasticity).*

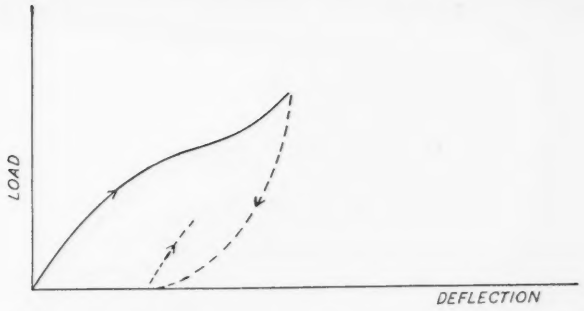

FIG. 5. *Load-deflection diagram (imperfect elasticity).*

Figure 6, and the load-deflection diagram is shown in Figure 7.

The deflection, in this case, is not constant with time, but the recovery is complete, although delayed as a result of the primary creep component. Similarly, the deflection is not linear with load since the delayed component (primary creep) is acting in addition to the immediate elastic component. This further emphasizes the importance of the shape or path of the load-deflection curve in determining any index of elastic performance.

It may now be observed that from the nature of typical original load-deflection curves obtained experimentally from textile fibers and structures, these materials are imperfectly elastic since the curves obtained reflect the summation of the effects of all three deflection components—that is, immediate elastic, primary creep, and secondary creep.

Textiles are seldom designed to withstand a single stress application of high magnitude. The conventional structures are likely to be subjected to long usage, and, during their lifetime, to experience a series of repeated stress applications and removals. To resist destruction the specimen must be capable of absorbing energy imparted to it upon stress application and of releasing this energy upon removal of the stress without the occurrence of failure.

The fundamental physical properties of materials govern their ability to absorb and return energy. Energy-absorption properties are a function of the load-deflection characteristics of the material. If the energy absorbed by a specimen upon load application is to be returned without appreciable loss upon load removal, then the basic requirement is one of elasticity in the classical sense.

Since energy absorption and return is a criterion of repeated stress performance, some index of energy-absorption properties is pertinent in the development of an elastic performance coefficient.

Energy, which is work done, may be defined as a function of the average force and the distance through which the force acts. Hence, the primary creep and the secondary creep (nonrecoverable deflection), as well as the instantaneous elastic deflection, contribute to the energy-absorption characteristics of a material.

It has been indicated that the secondary creep may be removed by means of a relatively few loading and unloading cycles [6]. For a material to resist destruction, it must withstand many cycles. Although secondary creep is an energy-absorbing component of the total deflection, its contribution under repeated loadings is negligible since it is removed in the course of the first few cycles. Both the im-

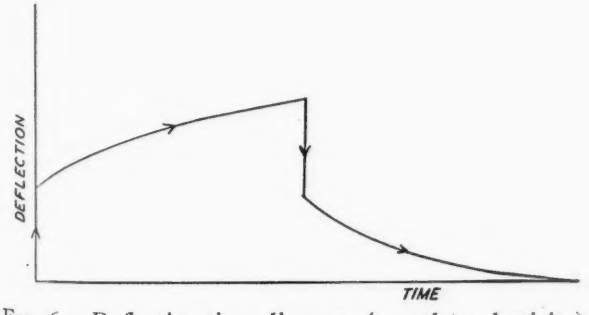

FIG. 6. *Deflection-time diagram (complete elasticity).*

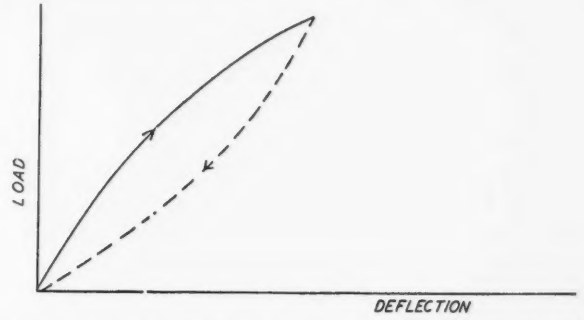

FIG. 7. *Load-deflection diagram (complete elasticity).*

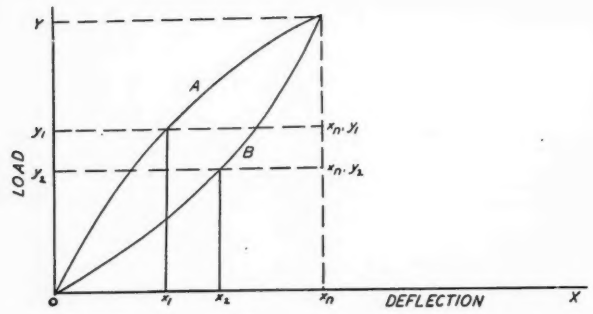

FIG. 8. *Load-deflection diagram (indicating slopes to mean).*

mediate elastic deflection and the creep deflection are recoverable upon load removal. They contribute both to the absorption and to the return of energy necessary for proper performance under repeated stress, the contribution of the creep deflection being dependent upon the rate of primary creep and the time intervals between stress cycles.

From the foregoing comments, it might be argued that a simple measure of the area under the original load-deflection curve of a material is a suitable representation of its energy-absorption properties. That this is not the case may be accepted in light of the following facts:

1. The one-time loading curve does not indicate the change in area effected by removing secondary creep. This is very important, since in many textile materials this change is considerable and is brought about by relatively low loads very early in the loading history of the material—that is, long before any type of failure is evidenced.

2. Although total areas under the curves representing two materials may be comparable, the rate of energy absorption may be vastly different, and, depending upon the end-use environment, it is the rate of absorption and return of energy which may be a limiting factor.

Therefore, the development of an index of energy-absorption characteristics must also take into account secondary creep and time effects.

Energy may be graphically represented as the area under a load-deflection curve. If, then, the load-deflection curve is constructed for a material subjected to a tensile loading, the area under the curve is a manifestation of the energy expended by the testing machine in straining the specimen. It is obvious that, all other factors being equal, a large deflection at a given load will yield a greater energy. Thus, a low average modulus of elasticity is desirable.

Textile materials do not have a clearly defined Hooke's-law range (stress linear with strain), and hence the conventional methods of determining modulus of elasticity are not applicable. However, a ratio of load to deflection expressed as a ratio of the mean ordinate of a load-elongation curve to the ultimate abscissa (slope to the mean) [4], is essentially a representation of an average modulus.

It is possible to take a mean slope instead of a slope to the mean in evaluating curves. This would yield the same slope for two curves starting and ending at the same point regardless of path. It is desired, however, to differentiate paths since they denote rate-of-change of properties; hence, the use of a "slope to the mean." (See Figures 8 and 9.)

Figure 8 represents two curves for which the slopes to the mean are to be determined. The area under curve A may be expressed as:

$$\int_0^{x_n} f_A(x)dx,$$

where $y = f_A(x)$.

The mean ordinate at x_1 may then be expressed as:

$$\bar{y}_A = y_1 = \frac{\int_0^{x_n} f_A(x)dx}{x_n}.$$

If this mean ordinate is now shifted along the

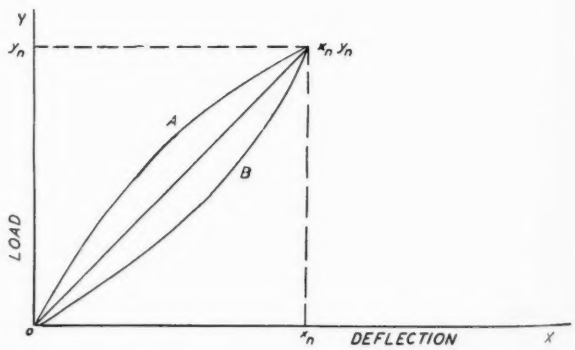

FIG. 9. *Load-deflection diagram (indicating mean slope).*

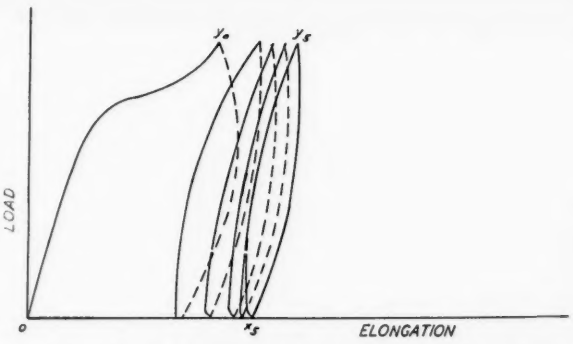

FIG. 10. *Load-elongation diagram (cyclical loading).*

elongation axis to x_n, the slope to the point $(x_n y_1)$ is the slope to the mean.

Similarly, the mean ordinate for curve B may be expressed as:

$$\bar{y}_B = y_2 = \frac{\int_0^{x_n} f_B(x)dx}{x_n}.$$

If this mean ordinate is shifted along the elongation axis from x_2 to x_n, the slope to the point $(x_n y_2)$ is the slope to the mean. Thus, the slopes to the mean for curves A and B are not the same and the paths are differentiated.

Figure 9 represents the same two curves A and B for which the mean slopes are to be determined.

The mean slopes of curves A and B may both be expressed as:

$$\frac{\int_0^{x_n} \frac{dy}{dx}\,dx}{x_n} = \frac{\int_0^{x_n} dy}{x_n} = \frac{\Big[y\Big]_0^{x_n}}{x_n} = \frac{y_n}{x_n}.$$

Hence, the paths are not differentiated.

Since a larger deflection at a given load yields greater energy, the deflection to load ratio will be used and termed inverse slope to the mean, in the development of the elastic performance coefficient.

The total deflection at any point on a load-elongation curve must be the sum of the immediate elastic, the secondary creep, and the primary creep components. The secondary creep component may be eliminated by repeated loadings. After subjecting the specimen to a sufficient number of cycles to remove this component, the final path of the load-elongation curve is modified as a result of its subtraction.

Upon the complete removal of secondary creep at a given load, subsequent load-elongation curves will be alike in shape and displacement—that is, they will superpose upon repeated loadings and unloadings. When such a condition prevails, the specimen is said to be "mechanically conditioned," all secondary creep now being absent.

If a hypothetical specimen, which has not been mechanically conditioned, manifests no secondary creep, the load-elongation curve for the original cycle and the conditioned cycle will be almost identical. In this case, a low average modulus of elasticity manifested by the initial loading cycle would depict the average energy-absorption properties under repeated as well as single stress application and removal; and the ratio of deflection to load (inverse slope to the mean) previously described would be a true measure of these properties. Thus high energy-absorption properties may be expected under repeated stress for a material manifesting a low modulus, no secondary creep, a large immediate elastic deflection, and high magnitude and rate of primary creep. For this special case, the original load-elongation curve may be utilized to predict these energy-absorption characteristics.

If, however, secondary creep is present, the effect of removal of this component by mechanical conditioning is to shift the hysteresis loop along the deformation axis and to decrease the inverse slope to the mean (see Figure 10).

Figure 10 is a typical repeated load-elongation diagram for acetate rayon, the conditioning load being, in this case, 90 percent of the ultimate load. The mechanical conditioning for this specimen was complete in five cycles, as is indicated by the reproducibility at the fifth cycle.

The path of the loading curve $x_5 y_5$ has been modified as a result of the subtraction of the secondary creep component from the original loading curve; and this, in turn, has resulted in a lower inverse slope to the mean and a corresponding decrease in deflection-load ratio.

Since the modified loading curve governs the energy-absorption characteristics of materials which are subjected to repeated stress, the magnitude of secondary creep is an important consideration.

To summarize, on the basis of the foregoing discussion, the properties desirable in materials subjected to repeated stress application are: (1) low modulus of elasticity; (2) large immediate elastic deflection; (3) high ratio of primary to secondary creep; (4) high magnitude of primary creep; and (5) high rate of primary creep [4].

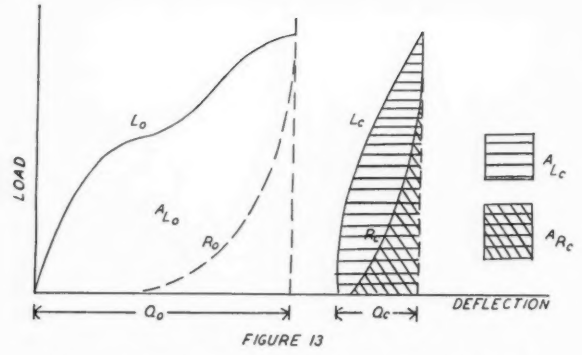

FIG. 11. *Load-deflection diagram (initial and conditioned cycles).*

With these points in mind, it is of interest to study the diagram for repeated loading.

Figure 11 depicts the original loading and conditioned cycles for acetate rayon.

L_o represents the path of the original loading curve, and R_o indicates the path of the original unloading or recovery curve; A_{L_o} is the area under the original loading curve, and a_o is the total deflection for the conditioning load. (The conditioning load is some percentage of the ultimate load, the magnitude of the percentage depending upon the end-use consideration.)

L_c represents the path of the loading curve at the conditioned cycle, and R_c represents the path of the recovery curve for that cycle; A_{L_c} is the area under the loading curve (L_c), and A_{R_c} is the area under the recovery curve (R_c); a_c is the deflection for the conditioning load at the conditioned cycle.

The shift to the right from the origin is a function of secondary creep and indicates the amount of permanent set resulting from the loading history. The change in inverse slope to the mean is an indication of changing stiffness and energy-absorption characteristics resulting from cold-working the specimen, and the average final width of the loop (conditioned cycle) is a function of the magnitude of primary creep.

The ratio of A_{R_c} to A_{L_c} is an index of the rate of recovery for the conditioned cycle since it is a function of the rate as well as of the magnitude of primary creep; a_c minus the average width of the loop is an index of the magnitude of immediate elastic deflection.

Thus from the diagram of repeated loading it is possible to evaluate the factors governing repeated stress performance. It now remains to develop a coefficient which will reflect properly the elastic performance characteristics of a material which is subjected to tensional repeated stress.

$\frac{a_o^2}{A_{L_o}}$, the inverse slope to the mean for the original cycle, indicates the energy-absorption characteristics for one-time loading. If a large portion of this energy absorption is the result of a secondary creep deflection it will contribute but little to the life-expectancy of the material under repeated stress, since the secondary creep may be removed in a few cycles. Hence, it is important to determine the extent to which $\frac{a_o^2}{A_{L_o}}$ is reduced at the conditioned cycle.

The ratio $\frac{a_c^2}{A_{L_c}} \Big/ \frac{a_o^2}{A_{L_o}}$ compares the energy-absorption characteristics which result from conditioning with the energy-absorption characteristics of the material before repeated loading. The deflection, a_o, and the area, A_{L_o}, are both proportional to the original gage length of the material tested. The deflection a_c and the area A_{L_c} are proportional to the sum of the original gage length and the permanent set. It is apparent, then, that in order to compare the energy-absorption characteristics of a conditioned sample with those of the material prior to repeated loading, the term $\frac{a_c^2}{A_{L_c}}$ must be calculated for the same gage length as the term $\frac{a_o^2}{A_{L_o}}$. This can be accomplished most conveniently merely by determining $\frac{a_c^2}{A_{L_c}}$ without consideration of gage length, and then dividing the result by the sum $1 + \frac{\%\text{ secondary creep}}{100}$. In the formulas

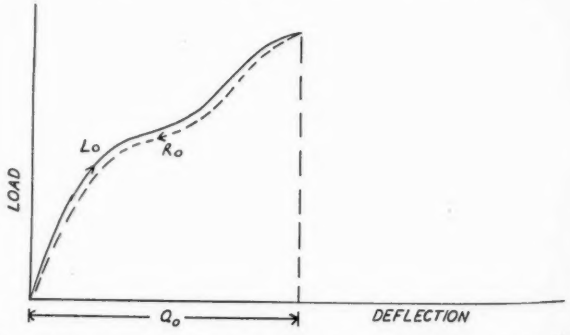

FIG. 12. *Load-deflection diagram (nonlinear material approaching perfect elasticity).*

which follow it is assumed that the term $\frac{a_c^2}{A_{Lc}}$ has been divided by this factor. Since the change in inverse slope to the mean results from the removal of secondary creep, this ratio reflects the effect of secondary creep.

The time effect of the recoverable deflection is also an important factor in the evaluation of the load-deflection characteristics, and hence the ratio given above must be modified by some factor which involves rate and magnitude of primary creep. As already discussed, the ratio $\frac{A_{Rc}}{A_{Lc}}$ represents rate of recovery and is a function of the rate and magnitude of primary creep. Modifying $\frac{a_c^2}{A_{Lc}} \Big/ \frac{a_o^2}{A_{Lo}}$ by $\frac{A_{Rc}}{A_{Lc}}$, the elastic performance coefficient (E.P.C.) in tension is obtained:

$$\text{E.P.C.} = \frac{\frac{a_c^2}{A_{Lc}} \frac{(A_{Rc})}{(A_{Lc})}}{\frac{a_o^2}{A_{Lo}}}.$$

Essentially, this coefficient depicts the elastic performance of the material, since it compares the energy-absorption characteristics of the conditioned cycle to those of the original, and then modifies this ratio by the recovery properties of the conditioned cycle.

Assume that there is a material which approaches perfect resilience and which manifests low magnitude and high rate of primary creep.

For such a material the recovery curve of the original loading cycle would approach the loading curve (see Figure 12). Secondary creep is absent, since the loop closes in the first loading cycle, and hence no shift from the origin takes place. L_o cannot equal R_o since the material manifests primary creep.

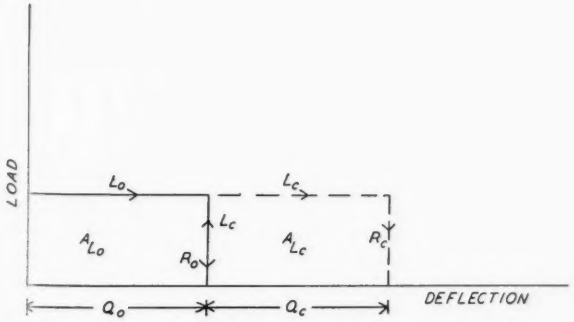

FIG. 13. *Load-deflection diagram (dashpot).*

The area under the recovery curve R_o approaches the area under the loading curve L_o—that is, $A_{Ro} \rightarrow A_{Lo}$. Since there is no shift of loop, only one diagram is available for analysis, and it may serve either as the original or the conditioned-cycle diagram. Therefore, the following identities and equalities exist:

$$A_{Ro} \rightarrow A_{Lo},$$
$$a_o = a_c,$$
$$A_{Lo} = A_{Lc},$$
$$A_{Ro} = A_{Rc},$$
$$\therefore \quad A_{Rc} \rightarrow A_{Lo} = A_{Lc}.$$

Substitutions in the formula for the elastic performance coefficient may be made thus:

$$\text{E.P.C.} = \frac{\frac{a_c^2}{A_{Lc}} \frac{(A_{Rc})}{(A_{Lc})}}{\frac{a_o^2}{A_{Lo}}} = \frac{a_c^2 A_{Rc} A_{Lo}}{a_o^2 A_{Lc}^2} \rightarrow \frac{A_{Rc}}{A_{Lc}} \rightarrow 1.$$

Hence, for such a case the elastic performance coefficient in tension approaches unity.

Assume now that there is a completely nonresilient material. Such a material would be depicted by the load-deflection diagram of a dashpot, as in Figure 13.

In this case, the load would be represented by the equation $F = KV$, where F is the force, K is a constant depicting the viscosity of the substance, and V is the rate of load application (velocity).

Upon load removal no recovery takes place. The entire deflection is due to plastic flow (secondary creep). It is obvious that repeated loading of such a material will simply result in an additional deflection, a_o, and area, A_{Lo}. There can be no recovery energy since the material exhibits only plastic behavior. Therefore,

$$A_{Rc} = 0, \quad A_{Lc} = A_{Lo}, \quad \text{and} \quad a_c = a_o.$$

$$\text{E.P.C.} = \frac{a_c^2 A_{Rc} A_{Lo}}{a_o^2 A_{Lc}^2} = \frac{a_o^2 \times 0 \times A_{Lo}}{a_o^2 \times A_{Lo}^2} = 0.$$

Hence, for such a case, the E.P.C. in tension is zero.

Thus it can be seen that the elastic performance coefficient is normalized and nondimensional, and expresses degree of elastic performance of materials on a percentage basis.

It is quite possible for two materials to exhibit the same E.P.C. in tension and yet differ in a very important property; namely, extensibility. To differentiate between materials in terms of this prop-

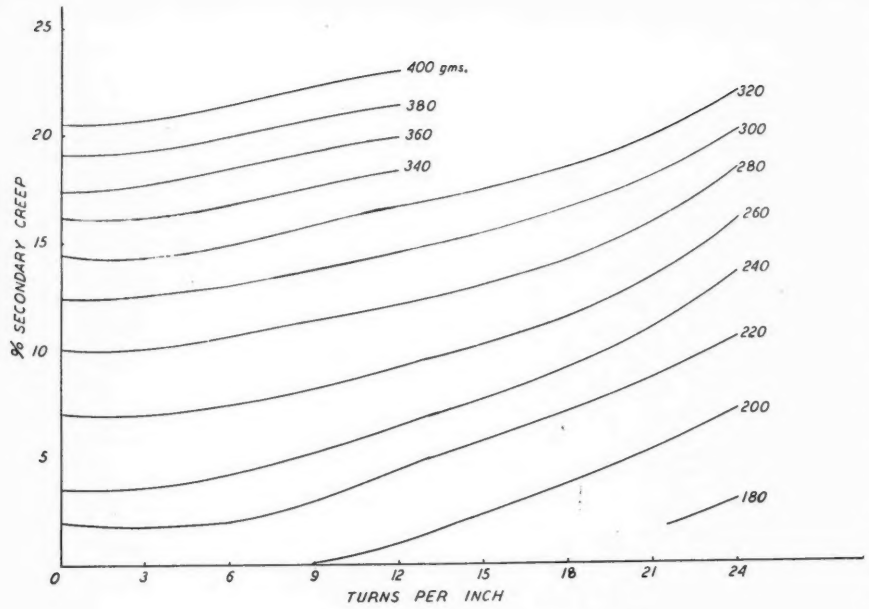

FIG. 14. *Secondary creep vs. twist.*

erty, the extensibility coefficient $E_t = \frac{a^2}{A_L}$ is used either for the original or for the conditioned cycle. This is a linear displacement index which is dimensional, the units being deflection per load. It may be desired to obtain a specific extensibility coefficient, E_{st}, which expresses extensibility per unit length of the material, thus: $E_{st} = \frac{a^2}{A_L l}$, for either original or conditioned cycle, where l = length of the specimen tested. Its units are deflection per load per unit length.

Discussion

To exemplify the use of the elastic performance coefficient, the following yarns were evaluated: acetate rayon, 300 denier, 104 filament, bright, containing 0.3, 1.5, 3.0, 6.0, 12.0, and 24.0 turns per inch; nylon type 300, 210 denier, 69 filament, in two constructions—namely, 210/1/3 8S, 6Z and 210/5/3 8S, 6Z. The 210/3 yarn was shrunk (Mertz box) at a temperature of 160°F and the 210/5/3 yarn at a temperature of 250°F.

In general, the repeated stress properties of a material vary with the maximum load (conditioning load) to which a specimen is cyclically subjected. Such tests are time-consuming since five repeated loadings are usually necessary for a reproducible action. For this reason only five specimens of each yarn were tested at each conditioning load and hence all average values given in this paper are the result of five tests.

Following repeated stressing to any conditioning load, a permanent set (deformation) which is nonrecoverable with time results. A high permanent set obviously means poor dimensional stability of a material under continued load application and removal. Permanent set may be of two types: geometric and inherent. Geometric permanent set refers to set resulting from rigid body motions which do not affect the molecular structure of the material—for example, crimp removal in a yarn or a fabric. Inherent permanent set is that which is produced by rigid body deformations as a result of which the internal structure of the material is altered—for example, secondary creep. The inherent secondary creep may, however, also be a function of geometry in the sense that the geometric form of a material has a definite effect on both the magnitude and the manner with which external loads are transmitted to the internal structure.

Values of the secondary creep, at various conditioning loads for each twist, were determined for 300/104 bright acetate rayon, as a percent of the original gage length. These values are given in Table I and plotted in Figure 14. Statistical analyses indicated that with the exception of a few points the 3.0- and 6.0-turns-per-inch yarns were insignificantly different from the 0.3- and the 1.5-turns-per-inch yarns. However, the 6.0- 12.0- and 24.0-turns-per-inch yarns were significantly different from each other. Hence, in drawing the graph of secondary creep versus twist per inch it was considered justifiable to draw the nest of curves essentially flat from 0.3- to 6.0-turns-per-inch. This curve was drawn by taking points from curves of secondary creep versus conditioning load and plotting them to a new set of coordinates. The general conclusions to be drawn from the graphs are:

TABLE I. REPEATED STRESS PROPERTIES OF CONTINUOUS-FILAMENT ACETATE RAYON

Gage length 15 in.	Conditioning load Grams	% of ultimate	% secondary creep	% corrected residual elongation	E.P.C.
300/104/0.3	232	50	3.0	23.8	0.492
	279	60	10.9	14.5	0.211
	325	70	15.5	9.2	0.140
	372	80	18.9	6.1	0.116
	419	90	23.0	5.1	0.105
300/104/1.5	233	50	2.8	23.5	0.519
	280	60	10.6	15.1	0.214
	327	70	15.0	8.4	0.149
	374	80	18.6	5.4	0.124
	420	90	22.7	4.8	0.101
300/104/3.0	228	50	2.8	23.2	0.448
	274	60	10.1	14.2	0.224
	319	70	14.6	9.4	0.149
	365	80	18.3	6.5	0.117
	409	90	22.4	4.1	0.100
300/104/6.0	241	50	3.0	24.9	0.471
	289	60	11.3	11.5	0.167
	337	70	15.4	8.8	0.124
	386	80	19.3	6.6	0.115
	434	90	23.9	4.7	0.096
300/104/12.0	238	50	6.2	19.8	0.388
	286	60	12.7	13.3	0.150
	332	70	17.6	7.8	0.124
	381	80	21.3	5.5	0.111
	428	90	25.3	4.6	0.093
300/104/24.0	177	50	2.4	25.0	0.443
	213	60	9.5	16.1	0.224
	249	70	14.5	8.9	0.153
	284	80	18.3	6.8	0.125
	319	90	21.7	4.7	0.103

NOTE: For Tables I and II all values are averages of five tests of five cycles each.

1. For all conditioning loads, the greater the twist the greater the permanent set in acetate rayon yarn. The effects of twist on permanent set are small until twist of about 6.0-turns-per-inch is encountered.

2. For all twists, the greater the conditioning load the greater the permanent set in acetate rayon yarn. The most rapid increase in secondary creep with load occurs at low loads.

The second conclusion applies to the untwisted yarn as well as to the twisted. That is to say, an increase in conditioning load causes acetate filaments to suffer increases in the permanent set. If such is the case, it is obvious why, at equal conditioning loads, a high-twist yarn has more secondary creep than a low-twist yarn. For equal conditioning loads, the internal stresses in the filaments of a highly twisted yarn are greater than those in the filaments of a yarn of lower twist, since the conditioning load is essentially the sum of the components of fiber loads parallel to the yarn axis. Therefore, if increase in stress on straight filaments causes an increase in the permanent set, then it is apparent that, for equal conditioning loads, the higher the twist, the greater the secondary creep.

If a material possesses secondary creep, the process of mechanical conditioning generally causes the final-cycle-to-rupture load-elongation diagram to differ from a one-time-loading-to-rupture diagram. Specifically, the elongation at a given load is less after conditioning than before conditioning. This means that the material has suffered an increase in its tensional stiffness. It is of value to know the elongation-to-rupture of such a material, since a large decrease in this elongation after conditioning reflects a large decrease in the energy-absorption characteristics of a material following repeated stressing in use. A material which shows a high elongation to rupture on a one-time loading basis may be selected for a particular end-use whenever such a large elongation is desirable. However, if this elongation is not attainable again and the end-use requirement is not a one-time use, then the choice of this material may not have been the best.

The percent corrected residual elongation is defined as the elongation to rupture following mechanical conditioning, expressed as a percent of the original gage length plus the permanent set resulting from mechanical conditioning. Since the permanent set in continuous filament acetate rayon varies with the conditioning load, it is to be expected that the corrected residual elongation will also vary with the conditioning load. Figure 15 shows the variation in the corrected residual elongation with twist for different conditioning loads. Important conclusions which may be drawn from this graph are:

1. For any twist, the greater the conditioning load, the less the corrected residual elongation for acetate rayon yarns. The most rapid changes in corrected residual elongation with load occur at loads between ⅔ gram per denier and 1 gram per denier.

2. For any conditioning load, the corrected residual elongation is constant with twist up to 6.0-turns-per-inch for acetate rayon yarns; following which,

higher twist causes a decrease in the corrected residual elongation.

Conclusion 1 merely indicates an inherent property of acetate rayon. Conclusion 2, however, definitely evidences a form effect, for which the basis of explanation is precisely the same as that given in the discussion of secondary creep. Since a given axial load on a high-twist yarn causes greater internal stresses than are present in a low-twist yarn, then the corrected residual elongation must be less for the high-twist yarn.

Since most textile materials possess primary and secondary creep, their mechanical properites depend on the previous loading history to which the specimen has been subjected. From the point of view of prediction of long-time properties in use, it would be desirable for textiles to have the same properties after continued stressing as they did before such stressing. This is so because continued stressing reflects a type of wear. A perfectly elastic material, such as an ideal spring, retains its original mechanical properties following continued load application and removal. The degree to which any material duplicates perfectly elastic material has been termed "elastic performance coefficient."

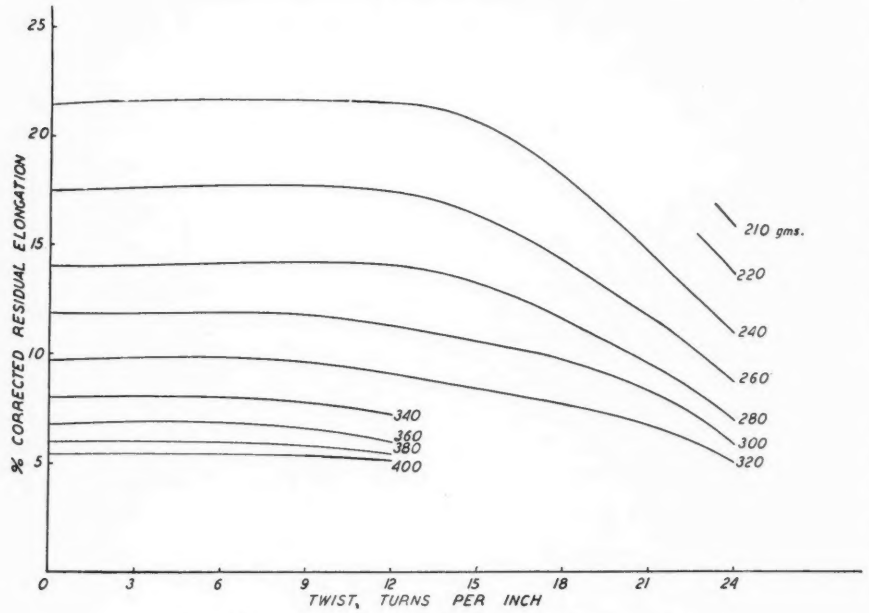

FIG. 15. *Corrected residual elongation vs. twist.*

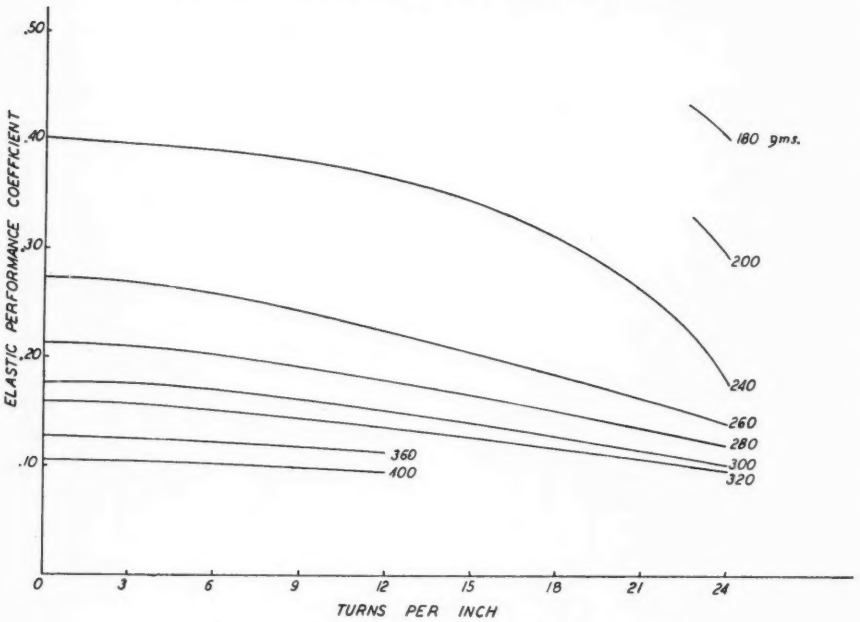

FIG. 16. *Elastic performance coefficient vs. twist.*

In this investigation five values of the elastic performance coefficient were determined for each twist studied and for each conditioning load used. Since the forces to which a textile material are subjected in use are unknown at present, it is necessary to establish the relationship between elastic performance and conditioning load. Figure 16 plots the coefficient against turns per inch for various conditioning loads. The important conclusions to be drawn from these curves are:

1. For a zero-twist acetate rayon yarn, the greater the conditioning load, the lower the elastic performance coefficient. This is also true for any twist.

2. For any conditioning load, the greater the twist, the lower the elastic performance coefficient. The greatest difference in elastic performance with twist occurs at the lower conditioning load.

TABLE II. REPEATED STRESS PROPERTIES OF CONTINUOUS-FILAMENT NYLON

Effective gage length [5] 9.50 in.	Conditioning load Lb.	% of ultimate	% secondary creep	% corrected residual elongation	E.P.C.
210/1/3 8S-6Z	2.6	25	1.7	20.3	0.453
Shrunk 160°F	4.9	50	3.8	18.1	0.440
Steam	8.8	90	6.8	15.9	0.437
210/5/3 8S-6Z	11.4	25	4.0	31.1	0.431
Shrunk 250°F	22.8	50	8.1	25.9	0.385
Steam	41.0	90	13.8	18.4	0.379

Since the coefficient reflects the effect of secondary creep, it should be clear that increase in the conditioning load would cause the coefficient to decrease since geometric secondary creep, owing to twist take-out, is more pronounced for highly twisted yarns than for low-twist yarns. Hence, it should be expected that at low loads the higher the twist, the lower the elastic performance coefficient. In addition, for equal conditioning loads, a high-twist yarn is subjected to a greater internal stress than a low twist yarn and since elastic performance for acetate varies inversely with stress, the decrease in the coefficient with the twist is explained.

Since the nylon yarns contain essentially the same twist, comparisons of repeated stress properties were made only on the basis of conditioning loads.

Data comparable to those previously obtained and discussed for acetate rayon are indicated in Table II.

Conclusions evident from these data are:

1. For both nylon yarn constructions, the greater the conditioning load the greater the secondary creep (permanent set).

2. For both nylon yarn constructions, the greater the conditioning load the less the corrected residual elongation.

3. For 210/1/3 nylon yarn construction, there are no significant differences between elastic performance coefficients with increases in conditioning load. For 210/5/3 nylon yarn construction, the higher the conditioning load, the lower the elastic performance coefficient.

The conclusions indicated in paragraph 3 may be explained by the fact that for the simpler construction —namely, 210/1/3—the *inherent* properties of nylon predominate; whereas for the 210/5/3 construction, *geometric* secondary creep, which results from the more complex yarn structure, affects the elastic performance adversely and is so reflected in the elastic performance coefficient.

The foregoing discussion of the variation of secondary creep, corrected residual elongation, and elastic performance coefficients with twist, load, and construction will be further expanded and explained by the application of stress analysis in a future paper of this series.

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Structure and Properties of Regenerated Cellulose

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THE x-ray patterns of regenerated cellulose were shown by Andress [1], Burgeni and Kratky [2], and Weissenberg [23] to be in agreement with a monoclinic unit cell which differs from that for native cellulose in interplanar distances and angles. The diffuse nature of the diagrams indicates that the distance through which lateral order extends is small. This low range of order may arise from the smallness of the crystallites [21] or from disorder within them [20]. On the assumption of perfect order within the crystallites, Hengstenberg and Mark [11] estimated from the width of the x-ray diffraction lines that the crystallite size in a sample of regenerated cellulose was 41 × 305 Å. If there is disorder within the crystal these dimensions will be larger and therefore these figures are only minimum values for the average dimensions of the crystallites.

Crystallites are recognized to be rigid structures, and hence in order to account for the strength and extensibility of cellulose fibers various investigators have assumed that the crystallites are separated by disordered or amorphous material [8, 13, 17]. Hermans [12] pictured the network structure of an unoriented and an oriented cellulose by the diagrams shown in Figures 1A and 1B. The dark blocks represent crystallites and the lines protruding from them represent ends of chains. It was recognized later that the chain length in the common celluloses was many times greater than the crystallite length suggested by Hengstenberg and Mark [11]. This led Frey-Wyssling [5] to conclude that one chain may belong to many crystallites. Then Kratky [15] presented a modified diagram of the structure of cellulose showing individual chains passing through a number of crystallites, as shown in Figure 1C.

In the work presented in this report the authors examined the network structure of cellulose by considering the probable mechanism by which the crystallites are formed, the structure resulting from this mechanism, and the properties of cellulose in terms of this network structure.

Mechanism of Crystallization and Formation of Network Structure

The formation of a regenerated cellulose from a solution involves changing the solvent conditions to reduce the solvation of the hydroxyl groups of the cellulose, thereby making it easier for these groups to bond with similar groups on other chains. After sufficient bonds are formed between chains, the solution changes to a gel, which undergoes syneresis as solvation is further decreased. The maximum degree of bonding or crystallization, as measured by x-rays, is observed only after syneresis is completed by drying.

Once a bond is formed between two chains, the portions of the chains near this bond are restrained from moving far apart, and the probability that additional bonds will form near the first one is increased. This effect leads to progressive bonding along a pair of chains in a manner similar to the closing of a zipper. The successive accumulation of chains by this process produces an organization similar to that which would be obtained by pushing a comb through the disordered material in one direction as far as it could go before the entanglement being pushed ahead of it prevented further movement of the comb, and then pushing it as far as possible in the opposite direction. Crystallization by this mechanism would produce a localized accumulation of disorder at the ends of the crystallites greater than that which is present in the original uncrystallized material.

Crystallite growth produces changes in the surrounding regions through which the crystallizing chains pass. A chain crystallizing in a manner similar to the closing of a zipper pulls the uncrystallized part toward the point of crystallization, and this

pulling on portions of the chains changes their orientation and order near the crystallite. As crystallization progresses, chain A of Figure 2 is pulled into the position shown by the dotted line. On the other hand, the slack or disorder in chains, which is for the most part directly forward from the point of crystallization, is pushed ahead, giving the high disorder at the ends of the crystallites. Other regions near the crystal will be affected to a degree intermediate between these two extremes. The increased orientation beside the first crystallite increases the probability that a crystal nucleus will form in that region and that the orientation will be parallel to that of the first one. This effect tends to produce one crystallite beside another, thus forming a chain of holes and crystallites, with the crystallites arranged as the rungs are in a ladder. The concentration of disorder at the ends of the crystallite spreads out much wider than the crystallite itself, and these spreading parts inhibit the adjacent crystal from growing longer than the first one. This effect tends to make the crystallites in a given row more nearly the same size. The pulling on chain A during the formation of the first crystallite of Figure 2 may produce a small amount of orientation in the region Y parallel to the original nuclei, thus promoting the tendency to form a second row of crystallites parallel to the first one. Fluctuations in the order of the cellulose just before crystallization will tend to cause deviations of these chains from straight lines, and the growth of several rows of initially parallel crystallites will eventually lead to the spherulitic structure shown in Figure 3. A high polymeric material oriented by stretching before crystallizing will produce crystallites which are oriented nearly parallel to the fiber axis, and the cooperative effect of producing crystallites side by side will tend to give a network structure like that shown in Figure 4, in which the black rectangles represent the crystallites. This model structure for a fiber is a typical average one on which is superimposed the disorder within the crystallites and the randomness in arrangement and in size of the crystallites.

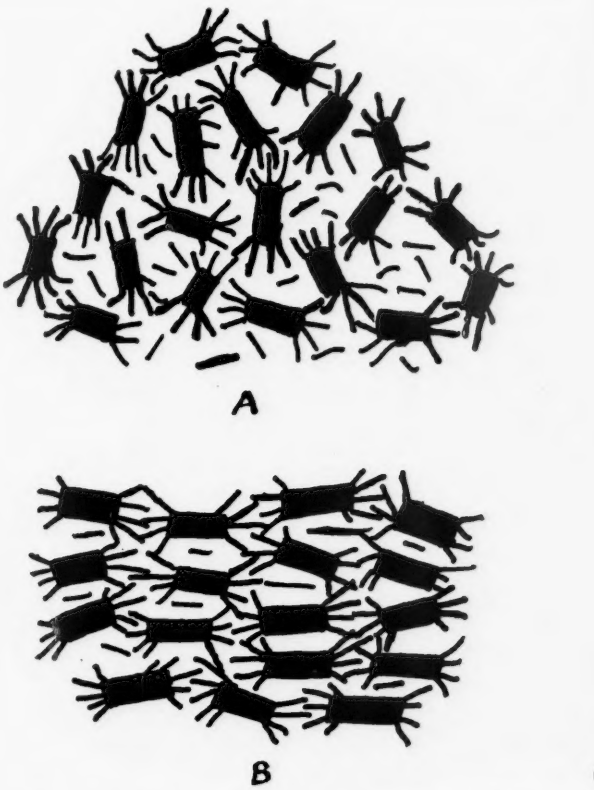


FIG. 1. *A—Micellar structure of isotropic cellulose. B—Micellar structure of oriented cellulose. C—Network of crystallites (heavy lines) and disordered regions with chains passing through several crystallites.*

Properties of Cellulose in Terms of Network Structure

Hydrolysis of Cellulose

The hydrolysis of cellulose proceeds rapidly at first, but after a period of time the rate becomes relatively slow. Various investigators [3, 7, 18, 19] have interpreted this phenomenon as being due to a reactive disordered or accessible portion and to a slowly reacting crystalline portion. Different methods of determining the degree of accessibility of cellulose give different absolute values but they all rate the celluloses in the same order [7].

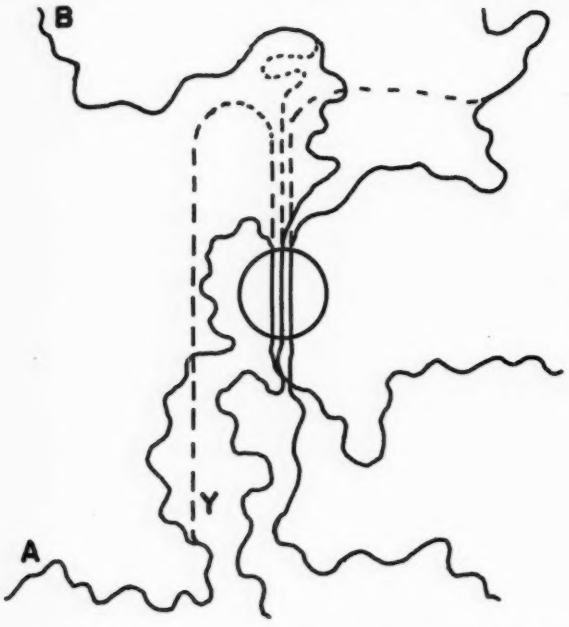


FIG. 2. *Changes in order around growing crystallite.*

Davidson [4] showed that the D.P. (degree of polymerization) of cellulose as measured by cuprammonium viscosity decreases initially very rapidly with time, but later it appears to approach a limiting value which is much lower for regenerated cellulose than for cotton. Figure 5 shows the change in cupriethylene-diamine viscosity * of a rayon tire yarn on hydrolysis in 1-percent sulfuric acid at 96°C. After a rapid drop the viscosity appears to approach a limiting value in about 8 hours. This is not a true limiting value since there is a very slow continued drop in viscosity. In the interval between 24 and 48 hours this drop is only about equal to the experimental error in the viscosity determination, and therefore we have arbitrarily taken the viscosity at 24 hours as a limiting value.

* Viscosity in centipoises of solution of 1-percent cellulose in 1*M* cupriethylene-diamine.

This rapid drop in viscosity can be accounted for by the cutting of a very small fraction of the bonds between glucose units in the amorphous regions. After a period of time when nearly all of the chains have been cut once in each amorphous region, only the exposed ends can be cut. This cutting off of ends will produce only a small change in viscosity. The weight-average limiting D.P., as determined from viscosities, should be approximately the average length of the chains passing through one crystalline and one amorphous region. The limiting D.P.'s of various rayons range from 75 to 100, corresponding to about 430 Å. to 500 Å. linear chain length. These values are of the order of magnitude to be expected if the crystallite length is about the 305 Å. minimum value suggested by x-rays for a regenerated cellulose. The periodic length from limiting D.P.'s should be larger than the minimum value from x-rays because part of the periodic chain length represents material in the amorphous region and because the minimum value is probably less than the actual value.

Electron-Microscopic Observation of Network Structure

A study of the surface of regenerated cellulose films was made using the electron microscope to

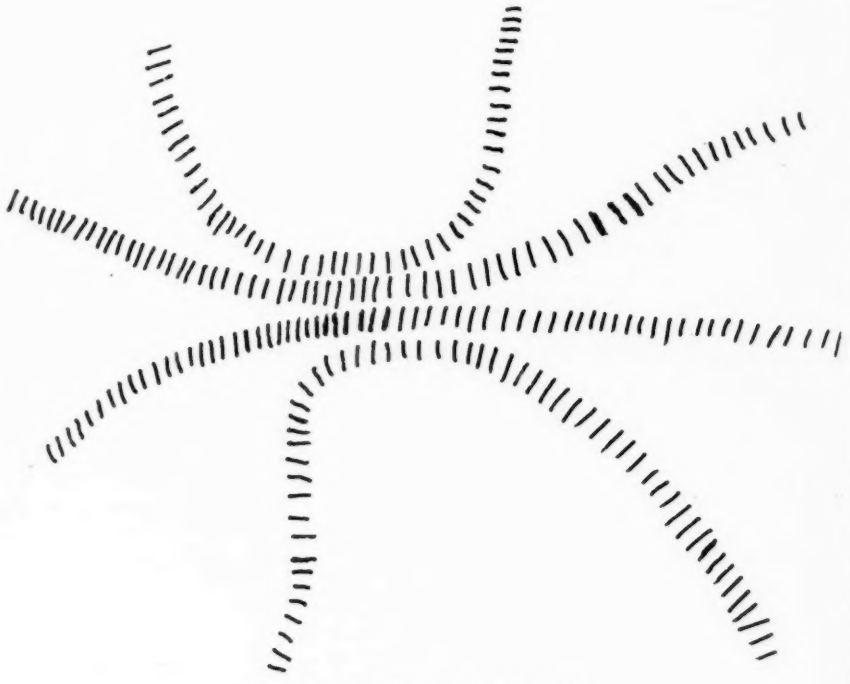


FIG. 3. *Structure of spherulite.*

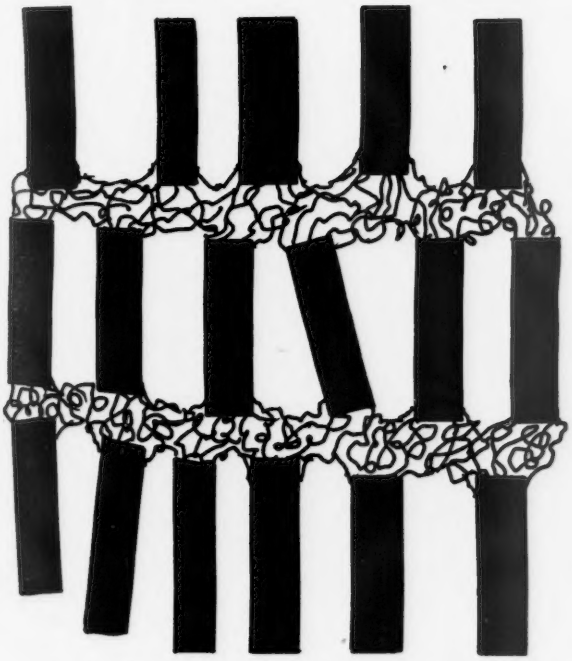


FIG. 4. *Revised network structure of cellulose.*

observe the network structure. Silica was evaporated directly onto the surface of the specimen, and the replicas formed were stripped from the surface of the sample, shadowed with gold, and photographed in the electron microscope. The technique of making replicas by evaporating silica directly onto the sample was described by Gerould [9] and of evaporating gold by Williams and Wyckoff [25]. This procedure gives negative replicas which have to be interpreted in a way different from that used for the more common positive replicas.

Figure 6 is an electron micrograph of such a gold-shadowed silica replica of the surface of a regenerated cellulose film showing an oriented network. Many of the particles appear to be joined together into fibrils with diffuse spots 300 Å. to 400 Å. apart. Moreover, many of these diffuse spots appear to be joined to similar spots in adjacent fibrils. The periodic distance of 300 Å. to 400 Å. agrees in magnitude with that estimated by means of data from x-rays and limiting D.P. on hydrolysis. The 2,000 Å. scale in the mircrograph is also the average linear chain length of the cellulose in the sample and this is about six times larger than the periodic distance along the chains. Shadowed replicas do not give directly the true appearance of the sample [10] but they do give the periodicities definitely. Further investigation, with shadowing from various angles, will be necessary to determine the relative width of the crystallites and holes.

Free Space in Regenerated Cellulose

The specific volume of all celluloses is greater than that of the crystalline material, as determined by x-rays. This difference in volume represents space not occupied by the chains. It may be caused by disorder in crystallites, free space between chains in more disordered or amorphous material, holes between crystallites, or larger holes produced by gas bubbles formed during regeneration. In almost all viscose rayons some elongated holes are observable with the optical microscope. Still smaller holes can be seen with the dark-field optical microscope and the electron microscope [14]. Holes having dimensions about crystallite size have been detected after they have been filled with gold [6].

The entrances to many of these voids in rayons are so fine that small molecules like those of benzene cannot enter or leave the cellulose except when it is swollen. The photomicrographs in the first column of Figure 7 show the dark-field cross sections of two high-tenacity rayons immersed in a mounting medium having the same refractive index as the cellulose. One type of yarn shows voids not penetrated by the mounting medium throughout the filament, but the other type shows voids largely in the skin. If these sections are swollen in water and the mount-

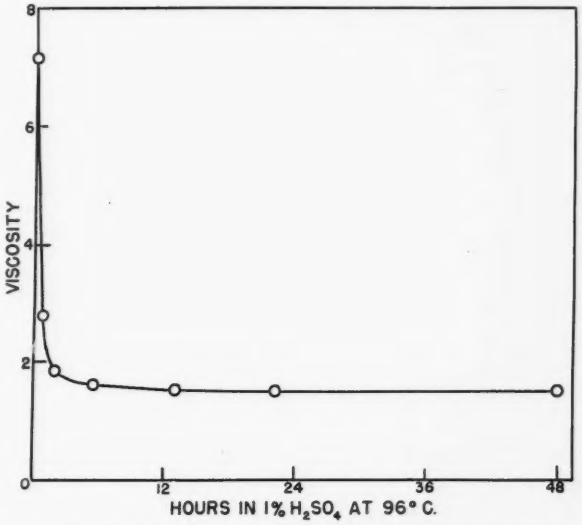


FIG. 5. *Effect of hydrolysis time on cupriethylenediamine viscosity of rayon tire yarn.*

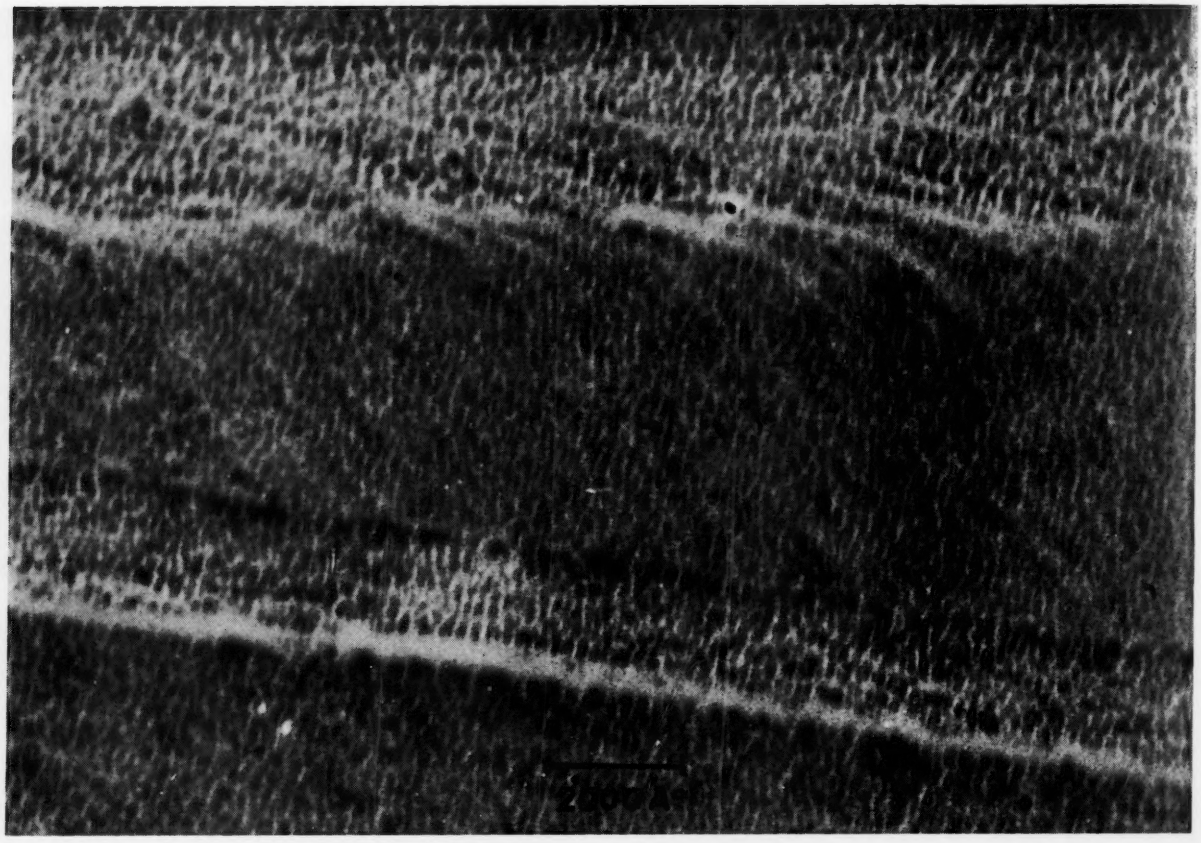


FIG. 6. *Electron micrograph of gold-shadowed silica replica of surface of regenerated cellulose film.*

ing medium is introduced by solvent exchange, the bright areas disappear, as shown by the two right-hand figures in Figure 7, which means that the voids are filled with the mounting medium. Staudinger and Dohle [22] showed that various nonpolar liquids can be introduced into cellulose by solvent exchange. Dr. K. C. Bass showed that a dry tire-cord rayon containing benzene introduced by solvent exchange loses only a negligible fraction of its benzene on heating for 24 hours at 100°C in a high vacuum. The holes are accessible to the benzene if the yarns are very highly swollen with liquid ammonia in a relaxed state and then dried. Such material has lost almost all of its crystallite orientation, indicating a considerable opening up of the network structure.

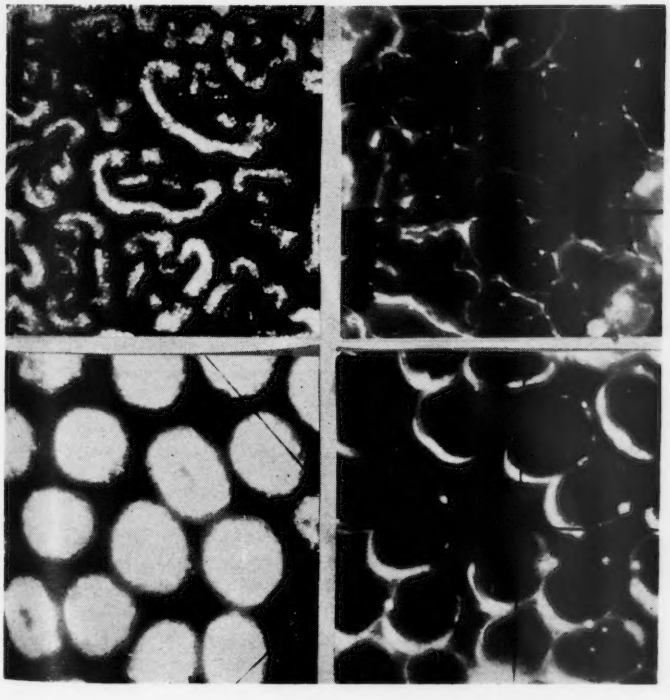
Breakdown Structures of Rayon Filaments

Lateral pressure on swollen filaments of the most highly oriented rayons produces longitudinal fibrils having a noticeably uniform appearance under the optical microscope [24]. Additional pressure or transverse shear breaks these filaments into still smaller ones. There are some points where these fibrils appear to join onto other fibrils or where smaller fibrils appear to pass from one large fibril to another, giving the appearance of a network structure. Less oriented rayons are more difficult to fibrillate and the network structures are much more pronounced. Figure 8 shows the network structure produced by the application of transverse pressure to a wet filament of textile yarn having moderate orientation. According to the network picture of crystallites joined by amorphous regions, a highly oriented rayon should fracture longitudinally more readily than laterally because fewer chains will be broken in the former type of rupture. In the less oriented rayons more chains will pass from one fibril to another, thereby making longitudinal fracture more difficult so that lateral fracture is more likely to occur. This effect makes the network structure more pronounced for the less oriented rayons. Cutting the chains between the crystallites makes lat-

eral fracture easier. Lovell and Goldschmidt [16] showed that hydrolyzed rayons fracture perpendicularly to the fiber axis as well as parallel to it on drying. Rayon fibers very highly swollen in either 8-percent caustic or 70-percent nitric acid frequently show lateral striations between crossed-nicol prisms, as shown in Figure 9, for a tire-cord rayon. No effects are visible in bright-field with the acid. The change in double refraction indicates a change in orientation periodically along the fiber. Most specimens of filaments showing this effect have a buckled appearance, which suggests that they tried to swell longitudinally but were restrained from doing so and therefore periodically buckled the network. Insufficient information is available on this effect to explain why it is periodic.

Tensile breaks in filaments tend to occur usually at right angles to the axis of the filaments, but near the rupture point of filaments broken in the Masland flex tester are found incipient ruptures making an angle of about 45° with the filament, as shown in Figure 10A. This effect can be most readily seen between crossed-nicol prisms, as shown in Figure 10B. Approximately 75 percent of the filaments in one type of rayon showed these 45° striations between crossed-nicol prisms. Many filaments show striations in one direction on one side of the filament and in an almost perpendicular direction on the other side of the filament, suggesting a spiral fracture. In the flex test, portions of the surface undergo repeated extension and compression. It is generally recognized [26] that most materials fracture at an angle of 35° to 45° with respect to the applied pressure. This suggests that the compression part of the flex cycle is largely responsible for the flex failure. The change in orientation near the incipient fracture can be explained by assuming an opening or buckling of the network in regions diagonally sheared under compression. Similar 45° striations have been observed between crossed-nicol prisms in filaments of tire cord which have failed in a fatigue tester. It is possible that fatigue failure in tire cords may be also largely the result of cyclic compression.

FIG. 8. *Photomicrograph of breakdown structure produced by lateral pressure on wet filament of moderately high-tenacity rayon.*



A B

FIG. 7. *Photomicrographs of cross sections of high-tenacity rayon with dark-field illumination. A—Surrounded by mounting medium. B—Mounting medium introduced by solvent exchange.*

FIG. 9. *Transverse striations in filament of tire-cord rayon swollen in 70 percent nitric acid.*

Stress-Strain Properties of Cellulose

A network structure of crystallites joined by disordered regions can elongate either by deforming the network or by stretching the disordered material between the ends of the crystallites. Both processes involve deforming the disordered material, but deformation of the network should take place more easily than stretching alone because of the leverage obtained by deformation of the network at its hinges. Figure 11A shows a network of crystallites joined by amorphous material. The stretching of such a material will elongate equally all regions between the ends of the crystallites without any motion of the crystallites with respect to their lateral neighbors. Figure 11B shows a network structure similar to that in Figure 11A except that two crystallites are missing. When this material is stretched the rows with the vacancies elongate little except at the vacant points, as shown in Figure 11C, because shear deformation of the network takes place more readily than stretching of the disordered material. If this process is carried far enough the network will close until the crystallites touch and then further stretching can occur only by stretching the disordered regions. Network disorder of any type produces inhomogeneous distribution of applied stress, thereby promoting shear.

Figure 12 shows plots of the extensibility (derivative of elongation in percent with respect to the applied stress in grams per original denier) against the elongation for a tire-cord rayon. The extensibilities were derived from the stress-strain curves obtained with a Scott IP–4 tester using a 40-inch sample length. The solid lines represent the actual data but the extensibility in the intermediate regions has been merely sketched in because of the difficulty in determining it accurately. Extensions of all the straight lines pass through the origin, so that for each curve, whether obtained from wet, conditioned, or dry yarn, there are two ranges of extensions in

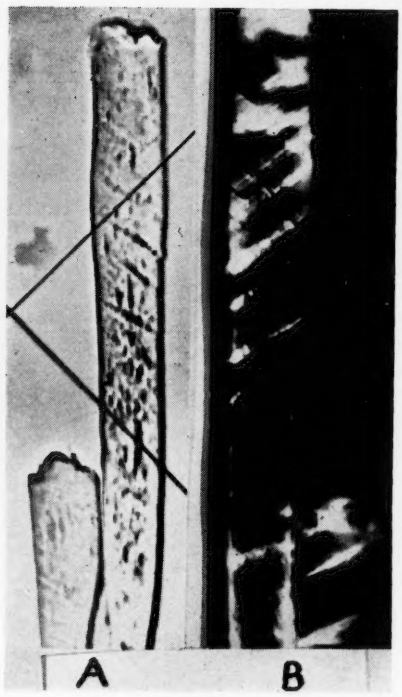


FIG. 10. *Photomicrographs of incipient breakdown near ends of rayon filaments broken in flex tester. A—Bright field. B—Between crossed-nicol prisms.*

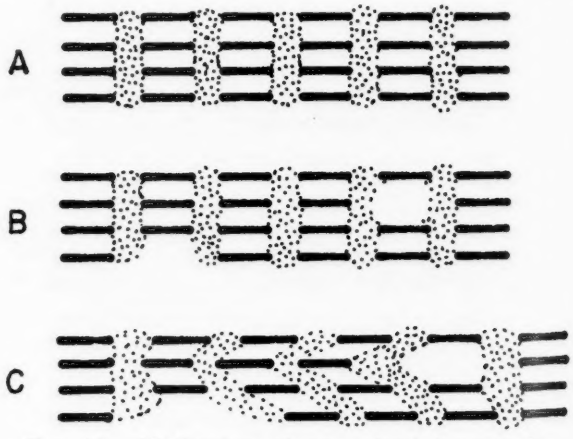


FIG. 11. *Mechanism of extension of networks.*

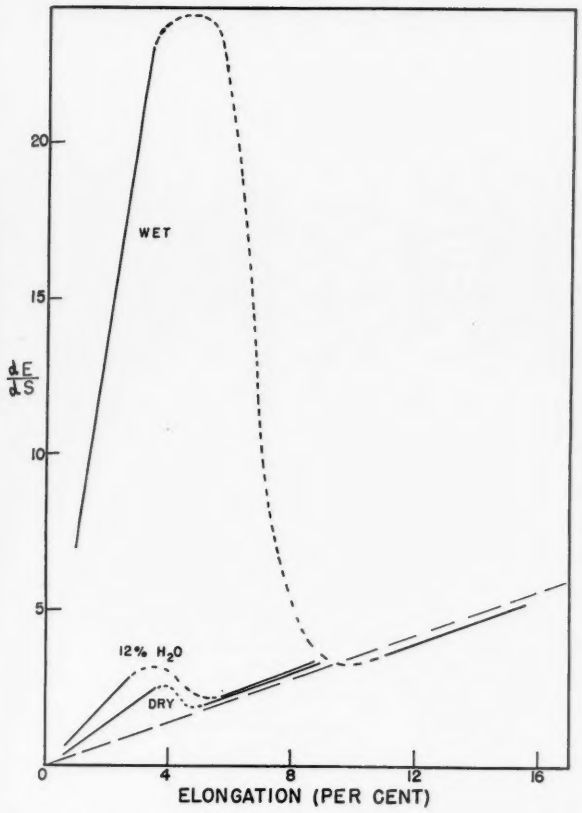


FIG. 12. *Extensibility as function of elongation for a tire-cord rayon.*

which the following relationship holds:

$$\frac{dE}{dS} = kE. \qquad (1)$$

E is the elongation, S is the stress, and k is a constant. The second straight line for all three curves

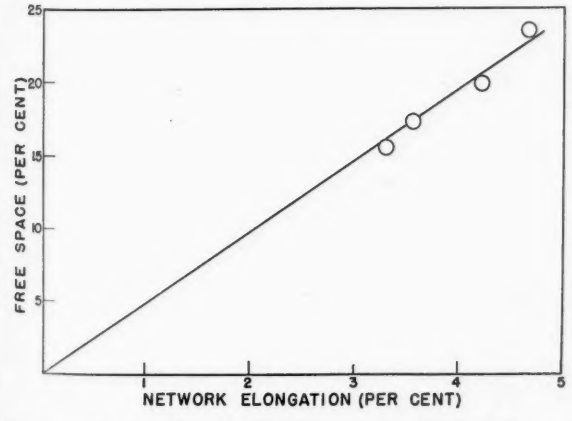


FIG. 14. *Free volume as function of network elongation for several types of rayons.*

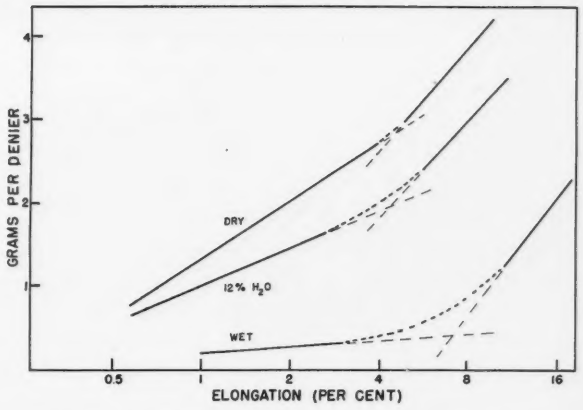


FIG. 13. *Plot of stress against logarithm of elongation for tire-cord rayon.*

can be represented by the dashed line almost within experimental error. The similarity of behavior in the first and second straight-line regions suggests a similarity in mechanism—namely, deformation of the disordered material, but the larger order of magnitude of the first extensibility suggests that it is greatly aided by an additional factor, such as the leverage effect of the network in deforming the disordered material.

When wet, fibers of regenerated cellulose have nearly the same crystallite density and fiber length as when dry; therefore, the increase in volume on wetting must be largely caused by an expansion of the network. The diameter of the tire-cord rayon whose stress-strain properties are plotted in Figure 12 is about 10 percent greater than the diameter which the fiber would have if there were no free

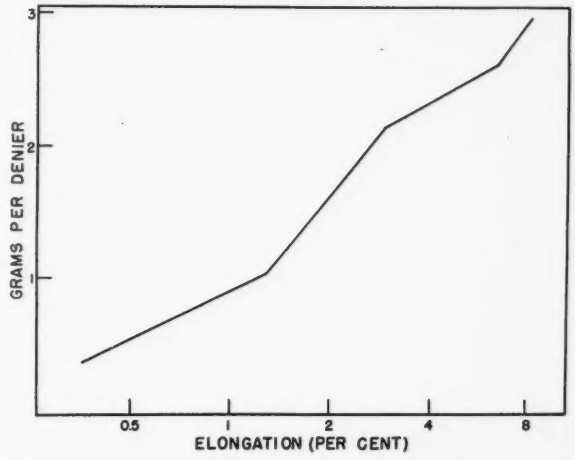


FIG. 15. *Plot of stress against logarithm of elongation after stress relaxation at constant extension.*

space in the fiber, and the diameter of a wet fiber is about 100 percent greater than its diameter when dry. This tenfold order of increase in the radial dimensions of the holes in the network on wetting-out should give a similar increase in leverage for deforming the hinges of the network. Therefore, the network extensibility of the wet fiber should be of the order of ten times that of the dry fiber. This is shown to be true for the first straight-line regions in Figure 12. The relatively small effect of moisture on the second straight-line portion of the curves suggests that the effect of moisture on the stress-strain properties of rayons is principally in expanding the network and relatively little in changing the extensibility of the disordered portions.

The differential equation (1) can be integrated to give

$$\log E = kS + c, \qquad (2)$$

where c and k are constants. Therefore, the data giving straight lines in Figure 12 must give straight lines in plots of the logarithm of the elongation against stress, as shown in Figure 13. The dotted portions of the curves correspond to the dotted portions in Figure 12 and they show the deviation of the experimental stress-strain data from the straight lines in the plots of Figure 12. The slopes and intersection point of the extended two straight lines have been found to be useful parameters for characterizing rayon fibers. The elongation at the intersection point has arbitrarily been taken as a measure of the network elongation. Figure 14 shows a plot of this network elongation against the free space of the fiber as calculated from the difference in volume of 100 grams of actual fiber and 100 grams of perfectly crystalline cellulose. A straight line drawn through the origin and the experimental points agrees within experimental error of the measurements. According to this relationship, a material with no free space has no network elongation. The plots of the logarithm of the elongation against the load also give similar straight lines for nylon and some other experimental polymeric fibers, when both stress-strain and creep data are used. However, it is possible to disturb this pattern by such treatments as stretching a tire-cord rayon to one-half its breaking strength and then holding it at constant length for 17 hours. Immediate testing of such samples on an IP–4 tester gave data approximated by four straight lines on the plots of logarithm of elongation against load, as shown in Figure 15. This suggests that such a fiber undergoes a network elongation, a stretching of disordered material, a second network elongation, and a final stretching of the disordered material. Various-shaped curves were obtained by stretching at different loads for the same length of time.

Summary and Conclusions

1. A mechanism of cooperative crystal growth in high-polymeric materials is proposed which tends to produce a superlattice of crystallites.

2. The limiting D.P. on hydrolysis of regenerated cellulose is interpreted as the average length of a chain passing through one crystalline and one disordered region.

3. Electron micrographs of the surface of regenerated celulose show the network structure with periodicities corresponding in magnitude to the crystallite length obtained from limiting D.P.'s and x-rays.

4. The free space of cellulose is due largely to holes in the network which become accessible to the diffusion of small molecules into the fiber when the network is expanded.

5. The network structure of rayon fibers may be broken down longitudinally, laterally, or diagonally, depending on the direction of the applied stress and the previous history of the sample.

6. The extensibility of rayon fibers is interpreted first as a deformation of the network structure of crystallites and disordered regions and finally as a direct stretching of the disordered material.

7. The very large increase in the wet extensibility of rayon fibers is largely due to the leverage gained by the expansion of the network.

8. The elongation required to collapse the network of a rayon is determined by the free space in the fiber.

Acknowledgment

The authors wish to acknowledge the assistance of Mrs. E. T. Oakley, Mrs. E. R. Johnson, and Mr. R. E. Spain of the laboratory of the Rayon Technical Division of the Du Pont Company in obtaining experimental data, and of Mr. E. T. Ellis and Mr. F. W. Gilbert of the Cellophane Division in preparing replicas for the electron microscope.

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An Orifice Test to Evaluate Yarns for Swelling-Type Water-Resistant Fabrics*

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Abstract

A technique is described for determining the relative closing capacities, largely a reflection of swelling behavior, of fibers in the form of parallel strands of yarn packed tightly in orifices, by observation of the seepage of water through the yarn. The method has been used successfully to predict the performance of cotton yarns for the type of water-resistant fabric whose utility depends largely upon "self-sealing" by swelling. Relatively wide variations in yarn construction have been shown to have little effect on closing capacity, whereas fiber shape and size, as well as swelling properties, have pronounced effects.

THERE has recently been greatly increased interest in fabrics that are intended to resist the passage of water, by means of swelling. Such fabrics may resist the passage of water inward, as in clothing [1, 9] or tentage; or they may resist the passage of water outward, as in unlined fire hose [6, 10] or in material for water bags and tanks. A fabric may be finished with a water-repellency treatment but may still rely on swelling to furnish a "second line of defense" after the repellency breaks down.

Research on the development of a swelling-type fabric soon disclosed the need for a method of comparing the swelling or closing capacities of textile fibers and yarns for fabrics in which the filling or the closing of interspace, or the stopping of flow of water, is a requirement. A method, here described, employing orifices, has been found to serve this purpose. It has been applied to yarns from different cottons; to yarns modified by mercerization or other chemical treatment; to cotton yarns whose swelling has been supplemented by the addition of swellable but insoluble materials; and to a lesser extent to yarns made from other cellulose fibers.

The orifice test being employed at the Southern Regional Laboratory depends upon the seepage of water under pressure through a bundle of yarn tightly packed in an orifice to simulate conditions in which the swelling of fibers upon wetting is intended to close the minute interstices in a fabric or other fibrous structure and thus reduce or prevent the passage of water by their "self-sealing" action. It seems quite possible also that some form of the orifice test may be applicable to textile materials for caulking and packings where swelling contributes to their effectiveness.

Previous Work with Orifice Tests

While methods closely related to the present orifice test have been applied to textiles for various purposes, no description has been found in the literature of such a method for measuring the comparative closing effects of fibers or yarns swollen by wetting, or for predicting what their behavior will be upon wetting after they have been made into cloth.

Balls [2], who was possibly the first worker to experiment with the swelling of cotton within a hole or orifice in a metal plate, measured changes in the cross-sectional areas of cotton hairs and noted that if the cotton was packed in tightly while dry, the hole could be completely sealed by the swelling of the hairs when exposed to a saturated atmosphere.

Hertel [7] has estimated surface (or fineness) by measuring the flow of air through confined fibers. Blow and Moxon [3] used an orifice for determining the wettability of textile fibers, whereas Cassie

* The material in this paper was presented in part by Charles F. Goldthwait before the Chemical Research Conferences, American Association for the Advancement of Science (Textiles), July 10, 1947, New London, New Hampshire.

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[4] employed the same type of apparatus to measure wool fiber diameters.

Applications of the present orifice method have already been mentioned in the literature although without detailed descriptions of the equipment or the test procedure. Goldthwait and Smith [5] reported it as a means of comparing the swellabilities of yarns; Goldthwait [6], for establishing the properties of a treated cotton yarn for unlined fire hose; and Reid and Daul [11], for testing partially carboxymethylated cotton yarns.

Apparatus

The orifices are drilled centrally in brass cylinders (Figure 1) that can be conveniently mounted in suitable pipe fittings. The orifice dimensions are: diameter, 0.125 ± 0.001 inch, and length, 0.5 ± 0.01 inch. The upper end of each orifice is slightly countersunk or "dulled" to avoid damage to the fibers when drawing-in the yarn sample.

The entire orifice test apparatus is illustrated in Figure 2. It consists of a brass tubing-manifold system, having 8 outlets for orifices, connected to a 5-liter water reservoir, equipped with a liquid level gage, filler plug, and air-relief valve. In service, the filled orifice cylinders are attached to the fittings beneath quick-opening brass gate valves. The necessary pressure can be obtained by means of a small air compressor, or may be supplied from a compressed air service line through a pressure-reducing valve. A wooden rack, shown in position in Figure 2, is used to facilitate the change of beakers by moving them simultaneously at the completion of a test period. A pressure gage and interval timer complete the apparatus, the whole being mounted on a portable framework approximately 3 feet wide, 2 feet deep, and 6 feet high.

Method

The method of making a test consists essentially in doubling a measured and weighed bundle of yarn over a fine strong wire, drawing it into the orifice, mounting in a fitting, submitting to water under pressure, and observing the amount that seeps through in an arbitrary period of time, such as 10 minutes.

When the yarn is limited in amount, or is raveled from fabrics, or if it is necessary for any other reason, the samples for testing are prepared individually, each from a sufficient number of 2½-inch lengths to make the required weight.

When yarn is available in continuous lengths, the following variation has been found more convenient: A skein of the yarn, after conditioning at 70°F and 65% R.H., is made of the required weight on a reel 54 inches in circumference. The yarn is drawn into the orifice with a looped wire by a method similar to that used by Blow and Moxon [3] (Figure 1). When all the orifice cylinders have been filled, the connecting portions of the skein are severed evenly at the face of each cylinder but the looped end is allowed to project about ⅛ inch to facilitate removal of the yarn at the completion of the test. The size of yarn sample and the amount of air space within it in the orifice have been chosen arbitrarily to permit a moderate amount of seepage through an ordinary cotton within the test period, but have been varied when required. Yarns can be compared on the basis of equal weights if the densities of the constituent fibers are equal; otherwise, the sample weights must be calculated to enclose equal air spaces if relative closing effects are being measured.

The air space, which supposedly represents the amount of swelling required to completely close the orifice, consists of many minute spaces between fibers of different strands of yarn, as well as between fibers within yarns, plus any appreciable void space inside the fibers themselves. The calculation of air space for orifice tests is based on Matthew [8], and is essentially the same as his calculation of air space in individual strands of yarn, from the density of the constituent fibers and the apparent density of the yarn as a whole. This calculation is expressed by the equation

$$S = \frac{d_1 - d}{d_1} \cdot 100, \qquad (1)$$

where S is the air space in the filled orifice, d_1 is the density of the cotton cellulose, and d is the apparent density of the cotton plug in the orifice, determined from its weight and the total volume of the orifice. If a value is known (or assumed) for the density of the fiber under investigation, the apparent density, d, required within the orifice to afford a given air space, can be readily determined, and the sample weight required may then be calculated from the known cross-sectional area of the orifice and the apparent density of the fibers, using any convenient length and taking into consideration the fact that the sample is

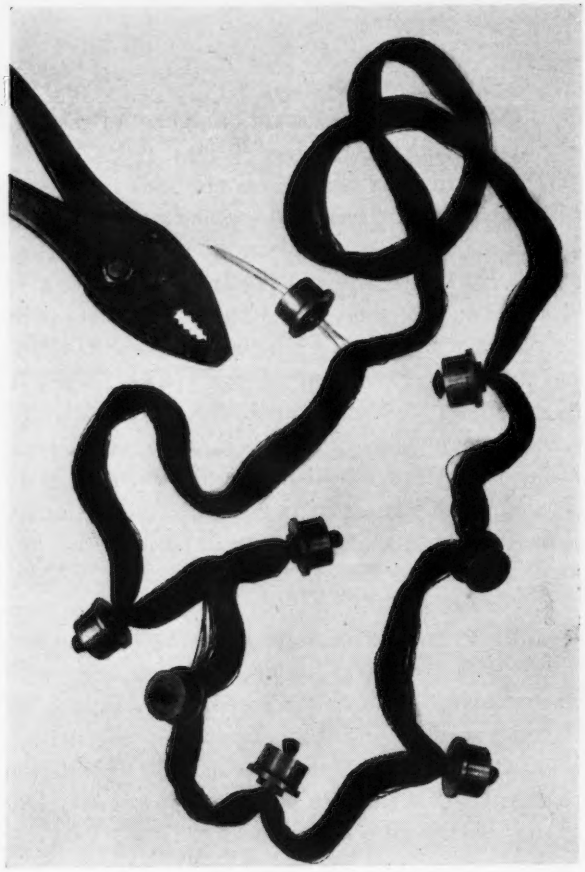

FIG. 1. *View of orifice cylinders showing method of drawing-in the yarn.*

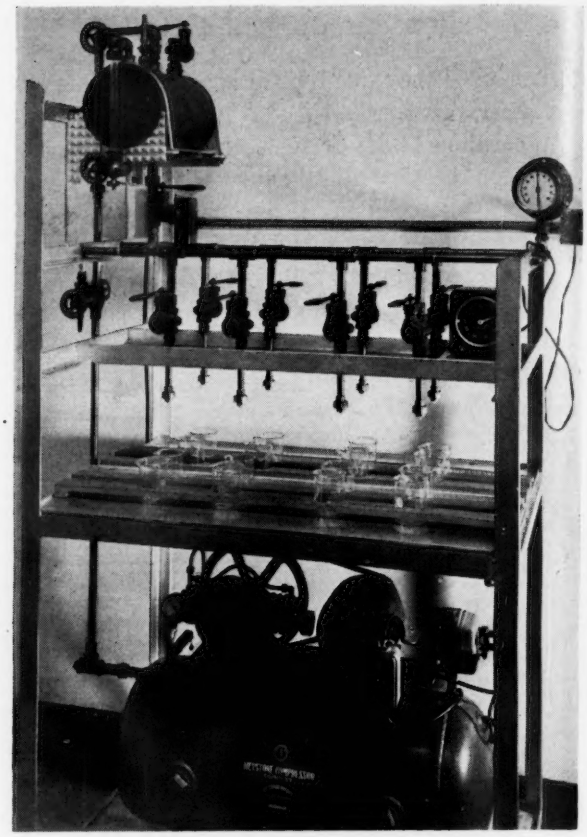

FIG. 2. *View of orifice test apparatus in operation.*

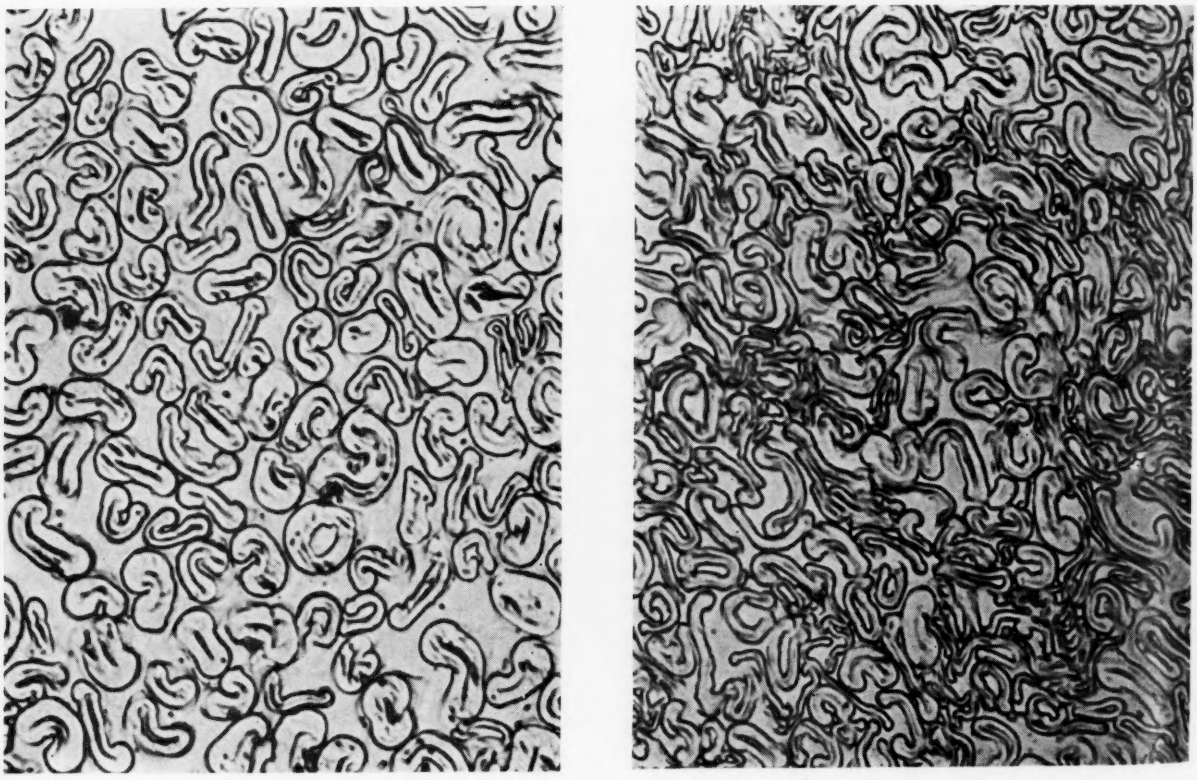

FIG. 3. *Cross sections of cottons differing in fiber shape, size, and maturity, with corresponding seepages. Left—Thick-walled, 83% maturity, 11.83 ml. seepage. Right—Thin-walled, 40% maturity, 0.96 ml. seepage.*

TABLE I. ILLUSTRATIVE LOWER PRESSURES ALLOWABLE BY CHANGED AIR SPACES

Test conditions		Seepage in 10 minutes		
Pressure (lb./in.²)	Air space (%)	Rowden cotton (ml.)	Wilds 13 cotton (1942 crop) (ml.)	Wilds 13 cotton (1943 crop) (ml.)
50.0	34	11.13	5.79	3.32
5.0	48	10.37	5.78	3.40
3.0	51	10.00	5.38	3.65
0.9	61	10.63	5.40	3.39

TABLE II. ORIFICE TEST SEEPAGES FOR 36/1 COTTON YARNS

Variety of cotton	50 lbs. pressure, 34% air space Seepage in 10 minutes (ml.)
Coker 100 Strain 4	12.5
Delta Dixie	7.4
Coker 100 Wilt-Resistant	1.6

TABLE III. EFFECT OF SWELLING ON SEEPAGE

Identification of yarn samples	50 lbs. pressure, 34% air space Seepage in 10 minutes	
	Dioxane (ml.)	Water (ml.)
Rowden cotton	46.0	11.84
Wilds 13 cotton	21.6	3.32
Highly mature cotton	61.0	11.83
Highly immature cotton	12.1	0.96

TABLE IV. CLOSING CAPACITIES, IN TERMS OF AIR SPACE, OF VARIOUS TEXTILE FIBERS WITH 5 LBS. OF PRESSURE

Kind of fiber	Air space (%)
Viscose rayon	53
Linen	40
Cotton	32
Cotton, warp mercerized	35
Cotton, with added swellable material	41
Nylon	18
Vinyon	15

TABLE V. EFFECT OF TWIST ON SEEPAGES THROUGH CARDED 12/1 YARNS FROM EMPIRE COTTON

Twist multiplier	Seepage	
	1st 10 minutes (ml.)	2nd 10 minutes (ml.)
1.75	2.64	2.64
2.88	2.67	2.60
3.50	3.10	3.06
4.00	3.67	3.59
5.12	3.91	3.83
6.25	4.69	4.40

TABLE VI. INFLUENCE OF YARN NUMBER ON SEEPAGE

Cotton variety	Yarn number	Seepage in 10 minutes (ml.)	Coefficient of variability (%)
Deltatype Webber	22/1	7.54	7.9
Deltatype Webber	36/1	7.34	3.2
Deltatype Webber	60/1	7.54	6.7
Stoneville 2B	22/1	2.20	5.1
Stoneville 2B	36/1	2.19	7.9
Stoneville 2B	60/1	1.98	14.9

doubled in the orifice. Since the weight of the sample is proportional to its length, the final result will be the same as though the calculation were made for the exact orifice length. The weight of sample, w (whether of short length or in the form of a skein), can be found from the equation

$$w = a \times \frac{l}{2} \times d, \qquad (2)$$

where a is the cross-sectional area of the orifice and l the sample length.

The larger part of the work at the Southern Regional Laboratory has been done at 34 percent air space and 50 pounds of pressure. For air space calculations the densities of conditioned cotton and other cellulose fibers are assumed to be equal and are taken, for convenience, as the round number 1.5. The test can be performed at lower pressures without changing either the actual or the relative values if, for each pressure, the amount of sample is adjusted to a corresponding air space (Table I), this relationship being represented by the equation

$$\log P = 12.22 - 6.87 \log S, \qquad (3)$$

where P is the applied pressure and S is the percentage of air space.

To make the test, the reservoir (Figure 2) is filled with distilled water containing 0.1 percent (by net weight) wetting agent * to insure rapid wetting. The orifice cylinders are attached to the fittings, the gate valves are opened, and all entrapped air is

* Dioctyl sodium sulfosuccinate has been used but it may react with the metal if allowed to stand in brass apparatus.

displaced by the liquid. (The samples fill the orifices tightly enough to prevent leakage until the pressure is applied.) The air-relief valve is closed, and the pressure is applied and raised to the desired point in the reservoir. The first seepage interval is timed from the appearance of the first drop, and the quantity of seepage through each yarn sample is measured by weighing in a tared beaker after each of two successive 10-minute periods. Each sample material is usually tested in all 8 orifices (Figure 2) with 2 successive observations in each; and usually two such sets of tests are run. All values shown in this paper are averages of at least 16 measurements.

The aid of a wetting agent is considered advisable, if the yarn wets with any difficulty, even though this represents an abnormal condition with respect to almost any practical use of the materials being tested. Otherwise, there may be uncertainty as to whether a given result has been affected by slow wetting and consequent incomplete swelling. The wetting agent probably also assures the complete removal of air from the yarn in the orifice.

Applications of the Method

The orifice test was first employed according to a somewhat different technique from that described above. In work on unlined fire hose [5, 6] the amount of linen yarn required to stop the passage of water through an orifice at 50 pounds of pressure was determined and a cotton yarn was then developed to equal it in performance by adding a supplementary swellable material until a weight of treated cotton yarn equal to that of the linen would also stop the seepage of water. Yarns selected as the best were found to give the most water-resistant fabrics upon weaving—that is, the results of the orifice test on yarns, carried out according to the technique of complete closing, were comparable to the performance of fabrics suitably woven from them.

It was found to be impossible, however, when testing ordinary untreated cotton yarns, to pull enough cotton into an orifice to stop the flow of water at 50 pounds of pressure. It was also noted that equal amounts of different cottons allowed different amounts of water to seep through, thus indicating that cottons are not all equal in closing capacity. Hence when the research was extended to other fabrics than fire hose, it was desirable to compare different cottons, and necessary to compare closing capacities indirectly by observing the amounts of seepage under conditions in which the flow was not stopped.

To illustrate the type of result obtainable with the orifice test in its present form, typical data have been tabulated.

For seepages observed with commercial cottons, shown in Table II, the ratio between extremes is rougly 8:1. Higher seepage values are seldom observed; but occasionally a cotton may yield a value low enough that extremes differ by as much as 12:1 (Table III). Such differences show that cottons may have very different closing capacities and may seem at the same time to indicate pronounced differences in swelling; the results, however, depend also upon other factors. For example, it has been found from observations on a great many cottons that thin-walled, flat fibers, commonly called immature, have more closing effect than rounder, thick-walled, mature fibers (Figure 3). Hence, although it may be possible to draw inferences regarding swelling from orifice seepages, the test is actually a measure of closing capacity due to the combined effects of swelling and of factors inseparable from swelling under the conditions of the test.

Other swellable fibers such as linen and rayon do not fall into a consistent series with the cottons, when considered from the standpoint of size and shape of fibers—apparently because of intrinsic differences in swelling capacity. The behavior of various textile fibers is illustrated by the data in Table IV, which show that different fibers were able to stop seepage at very different initial amounts of air space under comparable conditions. These percentages of air space were calculated from the weights (dry) of the fibers, found by experiment, which were necessary to prevent seepage in the orifice test under a pressure of 5 pounds, using equations (2) and (1).

The data in Table V, obtained on a series of comparable cotton yarns differing in twist, show that closing capacity decreases with yarn twist, probably owing to the fact that twist interferes with complete swelling. The difference is not great, however, within the limits of twist commonly used in spinning, nor, in the common range, does the size of yarn make any significant difference in seepage for a given cotten if the twists are comparable. This is clearly shown by yarns made from each of two cottons which differ considerably in wall thickness and in amount of seepage, each cotton being represented by three sizes of yarn (Table VI).

Discussion

That the orifice test reflects mainly the effect of swelling can be clearly shown by running a nonswelling liquid in comparison with water. For example, orifices loaded equally with suitable cottons allowed seepages of four to twelve times as much 1,4-dioxane (used as a nonswelling liquid without consideration of its viscosity) as of water (Table III), indicating that swelling reduced the flow of water in each case.

To explain the differing amounts of seepage of dioxane it is necessary to consider the capillary systems within the orifices because seepage, under the conditions of the test, appears to follow in a general way the laws of capillary flow, and may be greatly affected by the shape and size of capillaries as determined, in turn, by shape and size of fibers. The differing amounts of seepage of water (Table III) depend upon the added complication that the capillary systems are changed by swelling, but not necessarily in the same manner for different cottons nor to the same extent. It has not been possible to separate the effects of swelling from those of the capillary factors, but these variables need not be considered individually when making comparative tests of closing capacities of different cottons because the test observations represent the resultants of all pertinent effects and place the cottons in the correct order, with the relative closing capacities differing inversely as the seepages.

The orifice test described here is obviously subject to a number of uncertainties and errors. The most conspicuous error, which may amount to 1–2 percent, is unavoidable because the unit in loading an orifice is one strand of yarn, and it is often impossible to come closer to the required weight than plus or minus the weight corresponding to a large fraction of one strand. Numerous variations between fibers, natural and treated, would introduce error if the test were being used to measure true swelling. For example, the densities of different kinds of cellulose fibers differ slightly from one another, particularly in the air-dry or conditioned state when their moisture contents also differ. It is impractical, however, when the orifice test is being used to measure the closing capacities of commercial yarns, to take such details into account.

The method commonly used to check individual results—the taking of two consecutive 10-minute observations for each orifice—is illustrated in Table V. Usually the values are slightly lower on the second weighing, but they should be of similar magnitude to the first. Typical coefficients of variability are shown in Table VI for seepage values, each of which is an average of sixteen observations.

Finally, the validity of the method has been confirmed by tests on fabrics, no other method being known to be suitable for confirmatory tests of either swelling or closing capacities of yarns. Hence, in conclusion, it can be emphasized that the orifice method as described, although it still has inaccuracies, has proved its practical value as a laboratory test—it has been employed to predict successfully the order of performance of several series of experimental fabrics. These fabrics, representing a number of the variables considered here for yarn, will be discussed in subsequent publications.

Acknowledgment

Appreciation is expressed to various members of the staff of the Southern Regional Laboratory for help in the development of the orifice test and in the preparation of this manuscript, particularly to the Cotton Processing Division for manufacturing special yarns, and to the Cotton Fiber Research Division for cross-sectional photomicrographs of cotton fibers and yarns.

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Effect of Clamp Design on Fabric Breaking Strength

Warren T. Kelly and Margaret B. Hays

Aeronautical Materials Laboratory, Naval Air Experimental Station *

Abstract

The strength values of 10 fabrics, determined by the grab and raveled-strip methods and measured with the new Scott 2-inch fabric clamp and the standard 1-inch fabric clamp, were studied.

It was found that the 2-inch fabric clamp did not give more accurate results although the number of jaw breaks was reduced 30 percent.

The trend in aeronautical research in textiles is to develop stronger fabrics of lighter weight than those already in use. Consequently, a true indication of the breaking strength is of prime importance. An analysis of the breaking-strength determinations show many jaw breaks, which may not give the true strength of the fabric, as shown by Edelman [1] in a modified grab strength test in which the average of the jaw-break values was definitely lower than the average for acceptable breaks. Therefore an investigation of the effect of the clamp design on the accuracy of the test average and the number of jaw breaks was initiated by the Naval Air Experimental Station, as authorized by the Bureau of Aeronautics, Navy Department, Washington 25, D. C., on the new fabric clamp developed by Scott Testers, Inc. The Scott fabric clamps, one of the many clamps presented to a subcommittee of Committee D–13 of the American Society for Testing Materials now studying this problem, embody two special features: the length of the clamping surface (depth) is increased to 2 inches and the pressure is applied to the upper clamping surface forward of the center.

Fabrics and Test Procedure

Ten fabrics of various types, both coated and uncoated, and having a strength range of 80 to 550 pounds, were chosen for test. Each fabric was cut into specimens by the use of a split-plot Latin Square design so that the difference in the strength values for the new Scott clamp and the standard 1-inch clamp could be statistically analyzed.

The fabrics were tested for both grab and raveled strip breaking strength on a horizontal pendulum-type testing machine having a strength range of 0 to 1,000 pounds. The two sections of the split plot were tested by one operator on this testing machine on the same day to eliminate variation due to operator and day-to-day differences.

Results

The 2-inch grab-method strength results, as shown in Table I, were higher for the heavy coated fabrics, where the difference was highly significant according to the "t" test. However, the lighter cloth-

* The opinions expressed in this article are those of the authors and do not necessarily represent the opinions of the Navy Department.

TABLE I. RESULTS OF FABRIC ANALYSIS AND ANALYSIS OF THE STRENGTH RESULTS DETERMINED BY THE GRAB AND STRIP METHODS WITH 1- AND 2-INCH FABRIC JAWS*

Sample	Weight (oz./sq.yd.)		Count No.	*Grab Method* Strength (lbs.) 1-in. clamp	Strength (lbs.) 2-in. clamp	Percent difference	Test of significance "t" between clamp strengths	No. of tests (95% probability, 5% error) 1-in. clamp	No. of tests (95% probability, 5% error) 2-in. clamp	Clamp breaks (%) 1-in. clamp	Clamp breaks (%) 2-in. clamp	*Strip Method* Strength (lbs.) 1-in. clamp	Strength (lbs.) 2-in. clamp	Percent difference	Test of significance "t" between clamp strengths	No. of tests (95% probability, 5% error) 1-in. clamp	No. of tests (95% probability, 5% error) 2-in. clamp	Clamp breaks (%) 1-in. clamp	Clamp breaks (%) 2-in. clamp
Waterproof duck	18.0	Warp	46	262	275	+ 4.9	4.03‡	0.90	0.83	63	50	195	188	− 3.5	1.97	1.93	1.84	13	13
		Filling	27	161	173	+ 7.5	3.84‡	3.01	1.12	13	0	142	140	− 1.4	0.98	0.46	1.76	0	0
Parachute-pack fabric (cotton)	16.0	Warp	55	209	224	+ 7.2	3.47‡	1.00	3.97	88	75	139	142	+ 2.1	1.75	2.15	3.70	38	25
		Filling	39	133	144	+ 8.3	4.71‡	0.25	2.00	100	63	110	108	− 1.8	1.04	1.52	3.59	25	0
Cotton duck	14.7	Warp	48	242	251	+ 3.7	1.66	4.48	2.00	100	75	158	157	− 0.6	0.51	1.69	1.91	38	25
		Filling	32	198	208	+ 5.0	2.13	2.50	1.25	88	50	169	164	− 2.9	1.39	1.83	3.23	25	25
Jungle cloth, type A	13.8	Warp	48	150	154	+ 2.7	2.04	0.65	0.90	0	25	133	133	0.0	0.05	2.11	1.84	25	0
		Filling	307	270	282	+ 4.4	2.04	1.90	3.09	88	75	223	217	− 2.6	1.46	3.16	1.03	0	0
Jungle cloth, type B	8.1	Warp	58	86	87	+ 1.1	0.79	0.75	1.87	0	0	79	80	+ 1.2	1.23	1.26	0.75	0	0
		Filling	306	149	157	+ 5.4	2.04	5.69	1.98	38	75	133	134	+ 0.7	0.53	1.30	1.14	75	50
Life-raft fabric	13.2	Warp	103	218	223	+ 2.3	1.42	0.91	1.00	13	13	202	200	− 0.9	0.86	0.58	1.04	13	0
		Filling	97	188	192	+ 2.1	1.10	0.57	1.89	50	13	175	170	− 2.8	1.21	3.42	3.82	0	0
Carrying-case fabric	10.3	Warp	100	155	163	+ 5.2	3.90‡	0.88	1.54	50	0	131	127	− 3.0	1.07	0.32	3.09	0	13
		Filling	60	115	121	+ 5.2	1.86	2.50	6.36	63	25	106	107	+ 0.9	0.82	0.92	2.28	0	0
Parachute-pack fabric (nylon)	10.3	Warp	58	506	543	+ 7.3	7.40‡	1.08	0.12	88	88	332	368	+10.8	7.36‡	2.10	3.98	100	50
		Filling	45	405	448	+10.6	5.15‡	1.70	2.45	100	100	294	299	+ 1.7	1.72	0.81	0.26	63	13
Herringbone twill	8.7	Warp	73	135	136	+ 0.8	0.83	0.88	4.79	75	19	120	117	− 2.5	2.10†	1.84	1.96	0	19
		Filling	46	117	116	− 0.8	0.22	5.50	3.98	56	13	97	93	− 4.1	1.22	9.37	8.13	13	19
Uniform twill	8.7	Warp	117	182	180	− 1.1	0.77	1.78	0.91	100	100	158	152	− 3.7	1.46	3.18	7.00	63	38
		Filling	58	128	126	− 1.4	0.55	4.31	3.70	50	50	116	109	− 6.0	2.27†	4.65	3.56	25	13

* Strength tests based on 8 values, except those for herringbone twill, which were based on 16 tests.
† Significant difference. Probability of 0.05 for 8 tests = 2.14; 16 tests = 2.04.
‡ Highly significant difference. Probability of 0.01 for 8 tests = 2.98; 16 tests = 2.75.

ing fabrics did not give higher strength values when tested by the 2-inch clamp. In fact, the 2-inch grab-strength values for uniform twill were lower than those obtained with the standard fabric clamp.

The strip-method strength results (Table I) for both clamps were approximately equal except for the warp of a coated nylon fabric in which the 2-inch clamp increased the strength from 332 to 368 pounds. The elongation, not shown in Table I, also increased from 41.8 to 50.4 percent.

The number of jaw breaks varied considerably among the various fabrics, but none of the jaw breaks gave a test value definitely below the average value for that fabric.

The variation in test values for both clamps were not caused by operator or machine variability, which are known to exist, and were revealed when the tests, because of the required higher N value, were repeated later by different operators.

Summary and Conclusions

The higher apparent grab-method strength results for the 2-inch jaw were due to the fabrics and not to the clamping action. This was indicated by an analysis of variance on some of the grab-method results and the approximately equal strip-method test values for both types of jaws. The 2-inch clamp did not materially alter the elongation except in the case of a nylon fabric with a high elongation which caused the fabric to thin down and flow out the clamp, and thus stress the yarns more uniformly to increase the strip-method strength value.

The number of jaw breaks was reduced 30 percent by using the 2-inch clamp. However, the smaller number of jaw breaks did not improve the precision of the test average, for the number of determinations for a 95-percent probability with an allowable random sampling error of 5 percent was greater when the 2-inch clamp was used. A jaw break did not necessarily mean a low value, as some fabrics had jaw breaks with higher strength values than specimens with acceptable breaks.

Literature Cited

1. Edelman, N. B., TEXTILE RESEARCH JOURNAL 16, 268–74 (June 1946).

Book Reviews

Phenoplasts: Their Structure, Properties, and Chemical Technology. High Polymers, Volume, VII. T. S. Carswell. New York, Interscience Publishers, Inc., 1947. 267 pages. Price, $5.50.

(Reviewed by R. H. Kienle, American Cyanamid Company)

The treatment of the phenol-formaldehyde resins covered in this volume of the high-polymer series is excellent in that it logically proceeds from theory to commercial practice, supported with carefully chosen physical data. One would have to go a long way to find a better summation and analysis of the theoretical work done on the phenol-aldehyde reaction than that presented by the author in this volume. Although the book deals primarily with phenolic resins which are used in the plastics industry, others are included, such as Chapter XIII, "Oil-Soluble Phenoplasts," and Chapter XIV, "Phenoplasts as Ion-Exchange Resins." The treatment of the former seemed to the reviewer to be somewhat superficial, particularly in view of the more detailed way in which the phenolic resins were dealt with in the early chapters.

It is to be regretted that the same quality of paper is not used throughout the book. This comment is made because the volume is one of a series on a common subject, and uniformity from volume to volume is usually expected.

The book is recommended to both research and technical workers in the plastics industry, particularly those working with phenolic resins.

Vat Dyestuffs and Vat Dyeing. M. R. Fox. New York, John Wiley & Sons, 1947. 323 + viii pages. Price, $5.50.

(Reviewed by H. F. Clapham, E. I. du Pont de Nemours & Co.)

This recent book entitled *Vat Dyestuffs and Vat Dyeing* is considered a handy text both for practical dyers and for students. It appears to have been carefully planned and much literature searching has gone into its preparation. It is replete with references to source material in the text which will prove especially valuable to the student.

The book contains chapters on indigo and vat color composition and history, properties, application methods, printing and discharge, as well as a chapter on dyeing machinery, identification of vat colors, and a set of tables listing trade names of competing types.

Perhaps the most valuable feature of the book is that it brings together in one place much of the current information on the application and properties of vat colors and indigo. This alone will make the book a useful addition to any technical library on dyeing, since in many cases it will eliminate laborious searching through many publications for information. One caution is offered to the American reader—to remember that it is an English book and that the units of measure are English; this is particularly important in considering volume measurements, as the imperial gallon is larger than the U. S. gallon.

It is believed that a more satisfactory method of presenting the formulas in the book would have been to use percentage concentrations and percent on weight of material rather than the older recipe form of formulas.

Fachwörterbuch für die Farbstoffe und Textilhilfsmittel verbrauchenden Industrein (Technological Dictionary for Industries Consuming Dyestuffs and Textile Auxiliaries). German-English. Compiled by I. G. Farbenindustrie A. G. New York, Dictionaries, Inc., 1947. Price, $12.50.

(Reviewed by Howard J. White, Jr., The Textile Foundation)

This dictionary is a reissue under license from the Attorney General of one originally published by I. G. Farbenindustrie for its customers in the textile field. It contains some 20,000 words, primarily technical terms related to textile processing and, to a lesser extent, to chemistry, physics, and related industries such as leather and paper manufacture.

The reviewer is not qualified to pass on its com-

pleteness with respect to technological terms, but found it admirably comprehensive in fields of special interest to him. One minor point is extremely puzzling: The inclusion of the word "golfball" (English translation, "golfball") in a dictionary of textile terms, or, for that matter, any German-English dictionary at all, leaves the reviewer completely at a loss.

This book will be a useful addition to any library concerned with the textile or related fields.

Study of Agricultural and Economic Problems of the Cotton Belt: Hearings before Special Subcommittee on Cotton of the Committee on Agriculture, House of Representatives. Washington, U. S. Government Printing Office, 1947. 877 pages.

(Reviewed by Robert B. Evans, Southern Regional Research Laboratory, U. S. Department of Agriculture)

This publication presents the results of a comprehensive fact-finding program initiated at the request of Congress in 1945. The program was conducted by many representatives of the Department of Agriculture and other federal agencies, the Southern land-grant colleges and experiment stations, and other organizations concerned with cotton. It consisted of nine projects, including five relating specifically to cotton and four on the subjects "Adjustments Toward Efficient Agriculture in the South," "Southern Educational Problems," "Industrialization and the South," and "Health Situation in the South and Recommendations for the Future."

According to this study, the South's major crop, cotton, requires about five times as much man labor as wheat and about three and one-half times as much as corn to produce a given income. In order to produce cotton more efficiently and at the same time raise Southern living standards, it is stated that hand methods must give way to machine operation wherever conditions are favorable, that cotton production must be centered in those areas where it has a high comparative advantage, that size of farm units must be increased, and that population pressure on the land should be relieved by developing more Southern industries. In addition, in the project reports dealing specifically with cotton, which have been abstracted separately in this JOURNAL,* many recommendations are made as to how the marketing and utilization of this commodity can be improved.

As the most ambitious effort in its field, this general study is a highly valuable source of information for those interested in trends affecting cotton and the South. Although the publication is quite bulky in its entirety, brief summaries are given of the findings from each project.

Essays in Rheology. A Contribution to the Literature of a New Science. The British Rheologists' Club. New York, Pitman Publishing Corp., 1947. 103 + viii pages. Price, $3.00.

(Reviewed by Earl K. Fischer, Institute of Textile Technology, Charlottesville, Virginia)

The essays in this volume were drawn from the papers and notes of the speakers at a conference of British Rheologists held at Oxford in July, 1944. The material was revised and edited by a Publication Committee of the British Rheologists' Club, and although the essays carry no by-line, authorship is indicated in an introductory preface. It is evident that considerable thought went into the preparation of the final manuscript and the reader will probably be justified in assuming that the point of view is representative of that of the majority of British rheologists.

The first essay on metals, polymers, and liquids is based on the addresses by E. Orowan, R. F. Tuckett, and A. G. Ward. The second essay, by R. L. Brown, considers the relationship between compression and shear tests. A third essay, which completes the theoretical portion of the volume, was compiled by S. Whitehead and W. Lethersich to cover the subject of time variation of stress and strain. In these essays considerable understanding of special topics in rheology is presupposed. The authors maintain a critical point of view.

The remaining four essays are of more general interest and include a discussion of the recurring problems of nomenclature and the application of rheological methods to medicine, naval problems, and the fine arts.

* See page 138.

This small volume is by no means an introduction to the subject nor will it satisfy those seeking a complete exposition of the several topics covered, but to the physicist and the physical chemist the penetrating comments will be both useful and interesting.

Russian-English Technical and Chemical Dictionary. L. I. Callaham. New York, John Wiley & Sons, 1947. Price, $10.00.

This book fulfills a great need for the technician who has little or no knowledge of the Russian language and for all professional men who require a ready reference to Russian technical terminology. It is also an able guide for the student of the Russian language who has occasion to use or check technical words and terms.

Furthermore, the author has done an excellent job in the compilation of this dictionary. She is to be commended for her diligence and patience in working out a clear, concise presentation.

ABSTRACTS

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Reprints of the original articles abstracted in TEXTILE RESEARCH JOURNAL *are often available from the publishers. Otherwise, it may be possible to secure copies of the periodicals. Orders should be sent direct to the publishers.*

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The JOURNAL *is again offering to its subscribers reprints of the Abstracts and Book Reviews sections, printed on one side of the sheet so that the items may be clipped, pasted on cards, and filed for permanent reference. Subscriptions to this service for 1948 are $3.00 each. Orders for this special service should be mailed at once to Textile Research Institute, Inc., 10 East 40th Street, New York 16, N. Y.*

A list of periodicals abstracted, the abbreviations used in references to articles, and the addresses of publishers of English language publications is given in the January, 1948, issue, page 48.

CHEMICAL AND PHYSICAL RESEARCH

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Acetylene Chemistry

Acetylene chemistry. Anon. *Brit. Plastics* **19**, 258–65 (June 1947).

A review of the work of Reppe in Germany on acetylene chemistry. The production of vinyl ethers, cyclopolyolefins, N-vinyl-carbazole, 1,4-butinediol, propargyl alcohol, and acrylates is discussed. Brief mention is made of analogous reactions of ethylene. R. W. Eyler

Text. Research J. Feb. 1948

Cellulose Oxidation

Accelerated oxidation of cotton cellulose in presence of reduced Cibanone Orange R. G. D. Joshi and G. M. Nabar. *Nature* **159**, 711 (May 1947).

An investigation of the reduction potentials of vat dyes on cotton fibers and their influence on the acceleration of the rate of oxidation of the cellulose substrate by dilute sodium hypochlorite solutions is described. A close resemblance between the curve relating pH and oxygen uptake and that relating pH and the difference between the oxidation potentials of hypochlorite solutions and the reduction potentials of Cibanone Orange R is shown. R. W. Eyler

Text. Research J. Feb. 1948

Chemistry of High Polymers

The chemistry of high polymers. H. P. Staudinger. *J. Soc. Dyers and Colourists* **63**, 313–19 (Oct. 1947).

A generalized review of the principles which determine the performance of a polymer is given with examples of the factors influencing the properties of hardness, rigidity, plasticity, elasticity, and tensile strength. Intermolecular cohesion is discussed and the various sources for the forces of attraction are listed. It is said that polymer properties may be modified at various stages in the manufacture and by various means. Examples are given of the effect of substitution in the monomers. The polymer properties affected by changes in the polymerization process are said to have a controllable effect on the chain length and on polymer distribution. Emphasis is placed on the importance of copolymerization in changing polymer characteristics. Cross-linking and its effects are discussed under copolymerization with tetra-functional monomers. Physical treatment of polymers with heat or solvents to induce modification, and the chemical treatments also producing changes in polymer properties are described. Plasticization is discussed. 42 references.

J. A. Woodruff

Text. Research J. Feb. 1948

Polypeptides

Infrared spectra and structure of natural and synthetic polypeptides. S. E. Darmon and G. B. B. M. Sutherland. *J. Am. Chem. Soc.* **69**, 2074 (Aug. 1947).

A comparison is made of the infrared absorption spectra between 3,400 and 1,100 cm^{-1} of the synthetic polypeptide of Woodward and Schramm (*J. Am. Chem. Soc.* **69**, 1551) and denatured keratin, both in film form. Both show bands characteristic of the stretching vibrations of NH and CH, and deformation vibrations of CO, NH, and CH_2. Differences appear at frequencies below 1,450 cm^{-1}.

A. R. Macormac

Text. Research J. Feb. 1948

Structure of Starch

Configuration and packing of chain molecules of native starch in the β-modification. D. Kreger. *Nature* **160**, 369 (Sept. 1947).

Conclusions drawn from x-ray diffraction patterns are presented. A chain structure having 3 glucose units per period of 10.6Å. in threefold screw arrangement is proposed.

R. W. Eyler

Text. Research J. Feb. 1948

FIBERS: YARNS: FABRICS: MECHANICAL PROCESSES

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Cotton Fiber Property Relationships

Fiber properties determine combed-yarn quality. U. S. Dept. Agr. Production and Marketing Administration. (Processed.) Digest in *Textile World* **97**, 145, 147, 208, 210 (Oct. 1947).

This is the sixth report in a series covering a broad study on the relationships of cotton fiber properties to manufacturing performance and quality of manufactured products. The findings given in this report relate to strength and appearance of 60s and 100s combed yarn and percentage of picker waste, card waste, and total picker and card waste. Data have been analyzed showing the relative importance of strength, fineness, coefficient-of-length variability, percentage of mature fibers, grade of cotton, and upper quartile length to strengths of yarns and to yarn appearance. The importance of fiber length as a factor of cotton quality is discussed, one of the findings being that fiber length is less important to the strength of combed yarns than to that of carded yarns. How far it is safe and practical to reduce the factor of staple length and offset the reduction and increase of fiber fineness and strength remains to be determined. Until proved otherwise, fiber length should continue to be an important consideration in utilization of cotton fiber.

Text. Research J. Feb. 1948

Retting of Flax

The water-retting of flax; résumé of investigations from 1940 to 1945. W. L. Greenhill and Jean F. Couchman. *Australia. Council Sci. Ind. Research Bull.* No. **211**, 57 pp. (1946); cf. *C.A.* **39**, 4489[9] (through *Chem. Abstr.* **41**, 6726*d* (Oct. 20, 1947)).

This report presents results of studies to determine the effect of variable factors in Belgian retting techniques on Australian straw types, to simplify and improve these techniques, and to investigate new methods and special problems. Attempts to determine the end point of the retting process, which consists essentially in decomposition of cementing substances such as pectin, gums, and hemicelluloses, by physicochemical means, showed that pH observations were unsatisfactory for this purpose, but that increase in buffer capacity, as followed by electrometric titrations, could be taken generally as approximating the solution rate of cementing substances, and hence used to determine the end point. It was not considered necessary to introduce this method at commercial retting mills except to overcome process difficulties. Studies on the Belgian type of single ret showed that best results were obtained at retting temperatures between 30° and 36°C, with replacement of 10% of the retting liquor by fresh water every 24 hrs.; effects of the initial rinse and final wash were also studied. The Belgian type of double ret, although it improves the fiber grade, was not considered economical under present Australian conditions. Other factors studied included salinity of retting water, preremoval of seeds and weeds, and conditions of exposure and storage prior to retting. The design of commercial retting tanks is discussed in detail. 11 references.

Text. Research J. Feb. 1948

Crepe Fabrics

Processing and finishing rayon fabrics. R. A. McFarlane. *Dyer* **97**, 629–37; **98**, 91–8, 191–7, 293–305, 331–5 (June 20, July 18, Aug. 15, Sept. 12, 26, 1947).

A detailed description of rayon crepe fabric manufacture, starting with the viscose and acetate yarns and carrying through the stages of processing, is given under these headings: development of Courtaulds from silk mourning crepe to rayon fancy crepes; faults in crepe materials, pretreatments to modify figure or pebble; precontracting and scouring; handling in book form; star frame, winch, and continuous machines; scouring and delustering crepes; selection of dyeing machine; types of winch; factors which determine dyeing method; mixtures of acetate and viscose; final treatment for crepes; control of handle, dimensions, and appearance; development of anticrease and other properties. Photographs and diagrams are used to illustrate machines and operations.

J. A. Woodruff

Text. Research J. Feb. 1948

Cotton and Rayon Spinning

Effects of accessory influences on ring spinning of cotton and spun rayon. E. Honegger and A. Fehr. *J. Text. Inst.* **38**, 353–80 (Aug. 1947).

The first series of tests concerns the influence of anti-ballooning devices on the process of ring spinning. Usually these are vertical, flat metal plates, lattices between spindles, or wire rings concentric with the spindles. Strikingly important are values of winding tension and traveler friction, which shows that these quantities are hardly affected by separators. The traveler friction seems to be slightly reduced when the balloon is striking strongly against the separating plates. An oscillogram of the spinning tension, observed with and without separators, showed that an increase in the fluctuations of the tension was due to the intense brushing of the balloon, particularly at the lower position of the ring rail, against the separators. Most of the thread breakages occurred when the ring rail was down. A comparison of ring and plate separators showed that the anti-balloon-

ing rings resulted in lower yarn tensions. Numerous tensile tests, both with cotton and rayon made partly with free balloons and partly with close plate separators, showed that neither tensile strength nor elongation of the yarn is influenced by separators. The second series of tests deals with the conditions arising with eccentrically mounted spindles. Surprisingly, the results show that with an eccentric spindle the average traveler friction is preceptibly reduced. Winding and spinning tensions are similarly influenced but not to the same extent. Spindle eccentricity causes a large increase in amplitude of the variation of the spinning tension; also a considerable increase in the fluctuations of the tension, particularly at the upper position of the ring rail. With growing eccentricity of the spindle, the number of broken ends increases at points corresponding to high positions of the ring rail. However, small eccentricities seem to have little ill effect. Investigations on the influence of variable speed drives proved that the fluctuations in yarn tension due to the varying winding diameter could be avoided by a suitably adjusted spinning regulator. Regulating the speed for constant thread tension produces yarns of a high degree of evenness with respect to both elongation and tensile strength. On the other hand, by varying the speed in an inverse sense, possible brushing of the ballon against the separators can be avoided, but the yarn thus produced is very uneven. Another advantage of the spinning regulators, apart from extraordinary yarn evenness, is increased output. 10 of the most important references are summarized briefly.

Text. Research J. Feb. 1948 L. A. Fiori

Spinning Builder Setting

Fixers should know how to set builder. F. H. Gunther and Marcus Gross. *Textile World* **97**, 139, 141 (Oct. 1947).

The builder of the spinning frame when set for a straight wind should be started with the rack fully out. The builder allows the first layer of yarn to traverse the bobbin the full length of the stroke. The picking action of the pawl moves the rack toward the fulcrum of the builder arm and shortens the traverse of the yarn. The traverse becomes shorter for each stroke of the builder arm. Bobbin taper is controlled by the number of picks of the wheel moved by the pawl and by the number of teeth of the lay gear. Detailed instructions for setting the builder are given, together with explanatory diagrams.

A. L. Landau

Text. Research J. Feb. 1948

MISCELLANEOUS

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Mildew Preventives

Mildew preventives. Milton A. Lesser. *Soap and Sanit. Chemicals* **23**, 119–21, 123, 152–53 (Nov. 1947).

A review. 40 references.

Text. Research J. Feb. 1948

Wool-Scouring Wastes

Hypochlorite treatment of wool-scouring wastes—discussion. Joseph L. Campanella. *Sewage Works J.* **19**, 255–7 (1947) (through *Chem. Abstr.* **41**, 7125*b* (Nov. 10, 1947)).

Experiments have been done to adapt the hypochlorite process to a continuous-flow process by combining it with the centrifugal process, and, later, with better results, with a machine. The results of the experiments are surprisingly satisfactory.

Text. Research J. Feb. 1948

The hypochlorite process for treatment of wool-scouring wastes and for recovery of wool grease. Harry A. Faber. *Sewage Works J.* **19**, 248–55 (1947) (through *Chem. Abstr.* **41**, 7125*c* (Nov. 10, 1947)).

Wool-scouring wastes have an average analysis in parts per million as follows: grease, 8,500; suspended solids, 11,500; alkalinity, 6,700; oxygen consumed, 1,800; biochemical oxygen demand, 6,000; and N, 1,000. Acid cracking has been used for years but the process is highly odorous and the effluent is unsatisfactory. The centrifugal process recovers only half the grease and the effluent is unsatisfactory. Treatment of the wastes with lime and Cl gas separates the grease as a scum which when heated and filter-pressed produces a good grease recovery. The results, however, are quite variable with different wastes. The hypochlorite process, which has been most successful, consists in treating the wastes with Ca hypochlorite and aeration, which quickly separates the greases and soaps from the liquid in large curds. After 8 hrs.' settling the clear supernatant liquor is drawn to the sewer; the greasy sludge is acidified to pH 4.0–5.0, and a further separation of grease and water is caused by the liberated Cl gas. The sludge from this process is heated to 190°F and filter-pressed. Steam is applied to the presses until 70–75% of the grease is removed. The cake may be disposed of on land and dries without odor. The grease is steamed, treated with mineral acid, and separated; it contains 2% moisture and 5–10% free fatty acid and is now worth 11¢ per lb. Although the return from the grease will not pay for the total cost of treatment, it is a sizable item. The effluent has a biochemical oxygen demand of 500–600 parts per million but has been reduced 80–90%. Studies of its further treatment by biological processes are being made.

Text. Research J. Feb. 1948

Cotton Economics

Study of agricultural and economic problems of the cotton belt: hearings before Special Subcommittee on Cotton of the Committee on Agriculture, House of Representatives. Washington, U. S. Government Printing Office, 1947. 877 pages.

This publication presents the results of a comprehensive fact-finding program initiated at the request of

Congress in 1945 to make an overall study of problems facing the Cotton Belt. The program was conducted by representatives of the Department of Agriculture and other Federal agencies, the southern land grant colleges and experiment stations, and other organizations concerned with cotton. It consisted of 9 projects including 5 relating specifically to cotton and 4 on the subjects "Adjustments Toward Efficient Agriculture in the South," "Southern Educational Problems," "Industrialization and the South," and "Health Situation in the South and Recommendations for the Future." Reports on all of the projects are combined in the publication noted above but are also available separately. Those having specific reference to cotton are abstracted below. R. B. Evans

Text. Research J. Feb. 1948

Project II. The preparation for market and marketing of cotton and cottonseed (47 pp.).

Possibilities for increasing efficiency at gin include packaging of lint in standard-density bales, automatic mechanical sampling, permanent identification of bales relative to place of growth and variety, and more complete extraction of foreign matter. Futures prices do not always reflect to a sensitive degree the value of spot cotton because of the substantial losses involved in liquidating future contracts by delivery of actual cotton under the present system. In local cotton markets, marketing could be made more efficient by organizing production on a standardized variety area rather than a community basis, by stabilizing varietal characteristics, by expanding the program of official classification of cotton, and by development of a more effective market news service. About 80% of all domestic mill purchases are now based on official standards for grade and staple, but $\frac{1}{3}$ of the cotton also is purchased on the basis of area of growth and 10% on the basis of variety. Better means of identifying cotton bales are needed in order to facilitate purchase of cotton on the basis of area, variety, and lab-

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oratory tests, practices which are now growing. R. B. Evans
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Project III. Cotton goods production and distribution techniques, costs, and margins (146 pp.).

Of the consumer's dollar paid for clothing and household products in 1939, 7.5% went to the farmer, less than 3 % for ginning and taking cotton to mills, 49% to manufacturers, and 41% to wholesalers and retailers. Manufacturers' margins can be reduced by utilization of new and improved equipment, by increasing efficiency of labor by such means as in-service training, improved working conditions, and labor relations programs, and by vertical integration. Distribution efficiency can be increased by handling goods in larger volumes, by increasing self-service arrangements for retail customers, and by standardization. Comprehensive data on costs and possibilities for increased efficiency at each manufacturing and marketing step are given.
R. B. Evans
Text. Research J. Feb. 1948

Project IV. The competitive position of cotton by major end-use markets (98 pp.).

It is estimated that 7.7 million bales of cotton will be consumed in the United States in 1950, assuming moderate prosperity and a 25¢ price for cotton, as compared with 7.6 million bales in 1939, and 9.8 million bales in 1946. Cotton's share of the markets it serves will decline, from 55% in 1939 to about 45% in 1950. A greatly reduced cotton consumption is predicted if rayon becomes as good as cotton in launderability and durability. The quantitative importance of each quality characteristic is noted. In a section on prices it is stated that about 9.6 million bales of cotton would be consumed if the price were 12¢ per lb. but only 5.2 million bales if it were 40¢ per lb. In a section on advertising and merchandising it is stated that the cotton industry should keep currently informed on what is going on in each end-use market, that cotton is among the weakest of all fibers in promotional activities, that consumer preference for cotton can be built up by acquainting the public with cotton's problems and efforts to solve them, and by emphasizing cotton's merits. It is stated that the cotton industry needs to place greater emphasis on quality and should eliminate all products which do not give consumers real value. Need for a cotton fabrics library is emphasized. The report includes comprehensive data on consumption of cotton and competing materials in each use in 1939 with estimates for 1950. Factors affecting use of cotton in each end-use are comprehensively discussed. R. B. Evans
Text. Research J. Feb. 1948

Project V. Production studies of synthetic fibers and paper (114 pp.).

Much of rayon's rapidly increasing importance has been due to continued improvements, with two developments—staple fiber and high-tenacity rayon—of particular importance during the last few years. It would be unsafe for the cotton industry to assume that cotton will have any important margin of quality superiority in the years ahead. Because of large increases in cotton and wool prices since 1940, and only moderate rises in rayon prices, rayon recently has been priced more advantageously from a competitive viewpoint than ever before. It is unlikely that rayon prices will drop more than a few cents per lb. below wartime levels in the foreseeable future. Rayon production in the United States increased from 380 million lbs. in 1940 to 854 million lbs. in 1946, and expansion of capacity to an annual rate of 1,120 million lbs. by the fourth quarter of 1948 is expected. Synthetic fibers other than rayon are increasing rapidly in importance, with production totaling more than 50 million lbs. in 1946. In general, these fibers sell for a higher price than cotton or rayon and find markets only where their advantages in such properties as strength, elasticity, and resistance to microorganisms, acid, etc., are sufficient to warrant their added cost. The various types of noncellulosic synthetic fibers are discussed with reference to their development, properties, price, and utilization. As a group they are still in their infancy. Production and use of some of them can be expected to increase rapidly in the next few years, while additional types will be introduced commercially. Consumption of paper products which compete with cotton can be expected to increase because of technological progress in quality and a favorable price situation, but such increases will be at the expense of the long-time productivity of forest lands. R. B. Evans
Text. Research J. Feb. 1948

Project VI. Foreign-market outlets for American cotton and cotton manufactures (57 pp.).

World cotton trade in 1948-49 should involve 10 million bales, with the United States' share totaling 3½ to 4 million bales. Assuming continued improvement abroad, an optimistic conclusion would be that this trade would grow to around 12 million bales by the middle 1950's, with the United States' share unchanged. Exports of American cotton depend (1) upon the ability to sell at prices competitive with those of foreign-grown cotton, and (2) ability of foreign producers to obtain American dollars. If domestic cotton prices are artificially supported, it may mean the practical end to exports in a few years. Unusually high foreign demand for American cotton goods can be expected to decline after 1947. Centers of cotton textile production seem likely to continue to shift to cotton-producing centers, especially to South America, the Near East, and the Orient. With the intent of promoting the foreign market for cotton and textiles, it is recommended that the United States continue support of the United Nations and the trade-agreement program. Steps to improve marketability of cotton, to increase research relating to foreign market outlets for cotton, to provide further credits for financing cotton exports, and to encourage the fullest possible resumption of private trading are urged.
Text. Research J. Feb. 1948 R. B. Evans